НАУКОВІ ГОРИЗОНТИ

Засновник, редакція, видавець:
Поліський національний університет

Рік заснування: 1998

Рекомендовано до друку та поширення
через мережу Інтернет Вченою радою
Поліського національного університету
(протокол № х від хх 2023 року)

Свідоцтво про державну реєстрацію
друкованого засобу масової інформації
серії КВ № 24997-14937 ПР

Науковий журнал включено до категорії А Переліку наукових фахових видань України,
у яких можуть публікуватися результати дисертаційних робіт на здобуття наукових ступенів доктора та кандидата ветеринарних, економічних, сільськогосподарських і технічних наук зі спеціальностей: 051 – Економіка; 071 – Облік і оподаткування; 072 – Фінанси, банківська справа та страхування; 073 – Менеджмент; 075 – Маркетинг; 076 – Підприємництво, торгівля та біржова діяльність; 101 – Екологія; 133 – Галузеве машинобудування; 201 – Агрономія; 202 – Захист і карантин рослин; 203 – Садівництво та виноградарство; 204 – Технологія виробництва і переробки продукції тваринництва; 205 – Лісове господарство; 206 – Садово-паркове господарство; 208 – Агроінженерія; 211 – Ветеринарна медицина (наказ МОН України № 1166 від 23 грудня 2022 р.)

Журнал представлено у міжнародних наукометричних базах даних,
репозитаріях та пошукових системах: Інституційний репозитарій Поліського національного університету, AGRICOLA, CAB Abstracts and Global Health (CABI), Open Academic Journals Index (OAJI), Scopus, Index Copernicus, Реєстр наукових видань України, Національна бібліотека України імені В. І. Вернадського, Crossref, Directory of Open Access Journals (DOAJ), ERIH PLUS, MIAR, International System for Agricultural Science and Technology (AGRIS)

Адреса редакції:
Поліський національний університет
б-р Старий, 7, м. Житомир, 10008, Україна
E-mail: info@sciencehorizon.com.ua
https://sciencehorizon.com.ua/uk

SCIENTIFIC HORIZONS

Founder, Editorial and Publisher:
Polissia National University

Year of foundation: 1998

Recommended for printing and distribution
via the Internet by the Academic Council
of Polissia National University
(Minutes No. x of xx, 2023)

Certificate of state registration
print mass media
Series KV No. 24997-14937 PR

The scientific journal is included in category A of the List of scientific professional publications of Ukraine, in which the results of dissertations for the degree of doctor and candidate of veterinary, economic, agricultural, and technical sciences can be published in the following specialties: 051 – Economy; 071 – Accounting and Taxation; 072 – Finance, Banking and Insurance; 073 – Management; 075 – Marketing; 076 – Entrepreneurship, Trade and Exchange Activities; 101 – Ecology; 133 – Sectoral Engineering; 201 – Agronomy; 202 – Plant Protection and Quarantine; 203 – Horticulture and Viticulture; 204 – Technology of Production and Processing of Livestock Products; 205 – Forestry; 206 – Park and Gardening Management; 208 – Agricultural Engineering; 211 – Veterinary Medicine (Order of the Ministry of Education and Science of Ukraine No. 1166 of December 23, 2022)

The journal is presented international scientometric databases, repositories and scientific systems: Institutional Repository of Polissia National University, AGRICOLA, CAB Abstracts and Global Health (CABI), Open Academic Journals Index (OAJI), Scopus, Index Copernicus, Register of Scientific Publications of Ukraine, Vernadsky National Library of Ukraine, Crossref, Directory of Open Access Journals (DOAJ), ERIH PLUS, MIAR, International System for Agricultural Science and Technology (AGRIS)

Editors office address:
Polissia National University
10008, 7 Staryi Bvld., Zhytomyr, Ukraine
E-mail: info@sciencehorizon.com.ua
https://sciencehorizon.com.ua/en

НАУКОВІ ГОРИЗОНТИ

Том 26, № 7 2023

НАУКОВИЙ ЖУРНАЛ
Засновано 12 березня 1998 р.
Періодичність випуску: дванадцять разів на рік

SCIENTIFIC HORIZONS

Vol. 26, No. 7 2023

SCIENTIFIC JOURNAL
Year of establishment: Since March 1998.
Publication frequency: Twelve times a year

ЗМІСТ

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SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 26(7), 9-18

UDC 636.034. 082.2.4
DOI: 10.48077/scihor7.2023.09

Morphological profile of the ovaries of high-yielding cows on day 0 of the induced sexual cycle

Liliya Roman*
PhD in Veterinary Sciences
Odesa State Agrarian University
65012, 13 Panteleymonyvska Str., Odesa, Ukraine
https://orcid.org/0000-0002-4983-5418
Mykola Bogach
Doctor of Veterinary Sciences
Odesa Research Station of the National Research Centre "Institute of Experimental and Clinical Veterinary Medicine" of the National Academy of Agrarian Sciences of Ukraine
65037, 2 Svobody Ave., Odesa, Ukraine
https://orcid.org/0000-0002-2763-3663
Nina Dankevych
PhD in Veterinary Sciences
Odesa State Agrarian University
65012, 13 Panteleymonyvska Str., Odesa, Ukraine
https://orcid.org/0000-0001-8927-5219
Olena Bezaltychna
PhD in Agricultural Sciences
Odesa State Agrarian University
65012, 13 Panteleymonyvska Str., Odesa, Ukraine
https://orcid.org/0000-0002-4257-0699
Ievgenia Gurko
Assistant
Odesa State Agrarian University
65012, 13 Panteleymonyvska Str., Odesa, Ukraine
https://orcid.org/0000-0003-2485-9963

Article's History:
Received: 15.04.2023
Revised: 15.06.2023
Accepted: 10.07.2023

Abstract. An important part of reproduction management programmes on dairy farms is the detection of infertile cows and early re-insemination to achieve higher rates of pregnancy. The purpose of the study was to investigate the features of gonadal morphogenesis in high-yielding cows in the conditions of industrial keeping technology on day 0 of the sexual cycle *in vivo* in real time. Structural, comparative, and statistical methods were used, as well as biotechnical methods of palpation cyclic examination of ovaries with differential diagnosis of morphophysiological or pathomorphological

Suggested Citation:
Roman, L., Bogach, M., Dankevych, N., Bezaltychna, O., & Gurko, Ie. (2023). Morphological profile of the ovaries of high-yielding cows on day 0 of the induced sexual cycle. *Scientific Horizons*, 26(7), 9-18. doi: 10.48077/scihor7.2023.09.

*Corresponding author

indicators. The results of diagnostics of the ovaries of dairy cows (n=128) on day 0 of the induced cycle detected by step activity sensors showed a significant structural polymorphism of these organs of the reproductive system. It was found: from 66.67% to 30.77% of cows with a physiological course of the follicular phase of the cycle, i.e., on day 0, a preovulatory follicle or the beginning of ovulation on the ovaries (subject to a decrease in the number of cows suitable for insemination with increasing lactation duration from 50-75 days to 211-306 days (P<0.001). Hypogonadism was diagnosed in 19.45% of cows, and in 61.11% – ovarian dysfunctions with the manifestation of cystic follicular degeneration; 19.44% of cows at the time of the study had irreversible chronic adhesive processes of the genital tract tissues in the "ovary+oviduct" area (ovophoritis and ovosalpingitis in latent form), which allowed for pregnancy to occur, with a pronounced tendency to increase this gonadopathy with an increase in lactation (respectively: 50-75 days – 0.00%; 76-160 days – 22.22%; 161-210 days – 22.22%; 211 and more – 33.33%; p<0.05). The trend of influence of subclinical disorders in the metabolism of cows of the experimental herd on the indicators of the biochemical composition of blood serum and the symptom of ovarian dysfunctions was investigated. Thus, the *in vivo* morphological and pathological profile of the ovaries of high-yielding cows on day 0 of the sexual cycle was established, which allowed optimising the artificial insemination regime and reduce economically nonprofitless sperm consumption. The results can be used in the practical work of veterinary medicine doctors, researchers, and applicants for higher education in veterinary and biological science

Keywords: dairy cows; sexual cycle; ovaries; differential palpation diagnostics; follicles; hypogonadism; ovary dysfunction; gonadopathy

INTRODUCTION

The efficiency of reproduction of breeding stock remains an urgent issue for all dairy enterprises in the world and tends to expand the problem of reproduction by increasing milk productivity due to the biological conflict between the genetically fixed ability of cows to produce a large amount of milk and the physiological needs of the cows. Commercial milk farms in the United States, Western Europe, and Ukraine annually cull 27-34% of cows, mainly due to infertility (García-Ispierto *et al.,* 2019). These losses can only be eliminated by the intensive introduction of heifers into the herd. However, they are much more likely than cows to have problems with insemination and fertilisation after calving. Bardos *et al.* (2020) suggest that the shortage of repair livestock of the herd can be eliminated by modern biotechnical means (changing the sex of the calves towards the dominance of heifers, selection of embryos by sex).

According to Shebanin (2021), Sidashova *et al.* (2020), Borshch *et al.* (2020), in Ukraine, the main suppliers of commercial milk are large industrial complexes, where there is a high concentration of modern dairy cow breeds, which are characterised by a high genetic productivity potential.

According to modern biological concepts, the reproductive function pertains to healthy animals that exist in comfortable conditions of keeping. The cows' and heifers' reproductive system has physiological changes during the sexual cycle, the duration of which is on average 21 days and ranges from 16 to 28 days (Roman *et al.,* 2020). The day of growth of the dominant follicle and its ovulation with the release of the egg into the oviduct is considered to be day 0 of the cycle, or in a number of sources – day 1 (Denis-Robichaud *et al.*, 2018). A large number of resources in countries with developed cattle breeding have been devoted to the study of the specific features of reproductive ethology and physiology of cows in previous years, but due to significant changes in the industrial technology of milk production, rapid genetic progress of large-scale breeding of dairy cattle, the conditions of keeping and milking of modern dairy livestock have changed significantly. This could not fail to have an effect on the features of the reproductive function of cows, which began to form in the artificially created environment of industrial farms, which significantly differs from the natural environment which was common to cattle as a species due to long evolution (Ispada *et al.,* 2018; Danchuk *et al.*, 2020).

Modern technologies are designed for no grazing and tethered cows keeping in a confined space. From the perspective of a market economy, this is quite justified. However, they do not consider the biological features of cattle. As a result of separation from the natural environment, lack of living space, and excessive exploitation the productive life of cows is reduced to 1.5-2 lactations. Early culling of cows, regardless of their age and breeding value, occurs in 70-80% of cases due to irreversible pathologies of the reproduction organs. In the current conditions, the task is not only to preserve the livestock, but also to fully use its reproductive potential.

According to Ong *et al.* (2022), a long-term study of the sexual cycle of cows in countries with a developed dairy cattle breeding has contributed to a significant improvement in reproductive biotechniqes including methodological approaches to the selection of cows and heifers for insemination. However, indicators of the size and morphological features of the gonads of the sexual cycle in cows or heifers remain a factor limiting the number of animals suitable for biotechnical

procedures. At the same time, sources focus on improving the hormonal treatment schemes of animals.

Hansen (2019), Rodrigues *et al.* (2019) studied ovarian pathology in cows as the main cause of reduced fertility in dairy cattle and factors conducing to ovarian cysts. Monget *et al.* (2019) noted that the occurrence of cysts is caused by insufficient secretion of luteinising hormone during the arousal phase of the sexual cycle due to the inability of the hypothalamic-pituitary system to respond to estrogenic stimulation through positive feedback mechanisms.

Based on the researches, Kim (2018) found that follicular cysts are transient formations after loss of functional activity that undergo reverse development and are replaced by a new dominant ovarian structure that ovulates or transforms into a new cyst (the phenomenon of cyst change). The role of inflammatory processes in the tissues of the reproductive organs of cows in the disruption of ovarian function and cystogenesis was determined.

The breeding progress of dairy herds depends on the biological low fertility of cows and the duration of pregnancy, in addition, it is limited by the number and quality of gametes and the efficiency of reproduction of the herd. The purpose of this study was to investigate the features of gonad morphogenesis of highly productive cows in the conditions of industrial keeping technology on day 0 of the sexual cycle *in vivo* in real time.

MATERIALS AND METHODS

The study was performed in 2021-2022 on the number of dairy cows (imported purebred Danish Holsteins of 1-2 lactation), which belonged to a dairy farm that was a part of one of the agricultural holdings of Ukraine. The livestock was kept in a large farm in light hangar-type buildings that met modern zoohygienic requirements (climate control equipment). Dairy cows were kept in sections (100-120 animal units) with individual places for rest (equipped with rubber mats with an additional provision of sawdust bedding), for three times milking in an automated milking parlour with individual productivity accounting (electronic database "DairyPlan"). The animals received fully mixed fodder all year round, the content and ratio of feed nutrients corresponded to zootechnical standards for highly productive cows in accordance with the physiological state of the animals (9,450 kg of milk for 305 days of lactation).

Detection of cows for artificial insemination was carried out using the computer program for monitoring animal behaviour ("AfiFarm") using sensors attached to the hind limb of the animal. Considering a number of indicators of the step activity of cows, an integrated parameter corresponding to day 0 of the sexual cycle of cows was displayed on the monitor – an indicator of sexual arousal (heat) in the graphic image of the "reproduction windows", which showed the beginning, duration, and end of the period of sexual arousal of the cows, and the optimal time of fertilisation (insemination for a single spermodose into the cow's uterine cervix). The "reproduction window" had duration of 8 hours, which allowed the staff to perform artificial insemination for cows indicated by sensors at a comfortable time of the working day between milking individual groups of the herd.

To optimise the schedule of artificial insemination of groups of animals kept in different buildings, an additional study of detected cows on day 0 of the induced sexual cycle before insemination was performed by differential palpation diagnostics of morphofunctional and morphometric features of the ovaries, using a modified cyclic technique provided in sourses (Sidashova, 2017; Sidashova, 2021). Induction of cows` sexual activity in was performed according to the standard OvSyng hormone synchronisation protocol (day 0 – Ovarelin 2.0 ml intramuscularly; day 7 – Enzaprost 5.0 ml intramuscularly; after 56 hours – Ovarelin 2.0 ml intramuscularly; after 16 hours – artificial insemination on day 10 day of the scheme).

The study used comparative structural, statistical, and biotechnical methods. The test samples were the cows' ovaries of on day 0 of the induced sexual cycle, which were examined *in vivo* using a differential palpation technique, considering the indicators of computer tracking of the step activity of cows. During the rectal palpation of the ovaries we revealed the cows is in libido for artificial insemination according to the following parameters, which are given in detail in the previous studies of the authors: the size of the gonads conformity in length-width-thickness of ovomorphometry and morphological formations of the gonad to the species norm, cm; the presence of signs of a preovulatory dominant follicle or ovulated follicle on one or both ovaries for typical tactile symptoms, which is shown in our previous studies (Roman *et al.,* 2020). In the presence of symptoms of a violation of the ovarian follicular layer, characteristic signs of pathologies were noted: degenerative changes in the follicles (single or multiple follicular cysts).

Separately, the hypotrophy of the ovaries was noted, when their size and palpatory structure did not correspond to the species reference indicators, which characterised hypogonadism of both ovaries. The hypotrophy of one of the gonads, while compliancing to the normal morphology of the second, was determined to be the temporary inverse phenomenon of functional asymmetry (Roman *et al.,* 2020). Differential palpation diagnostics determined irreversible tissue changes in the ovaries and oviducts that were characteristic of animals with chronic symptomatic infertility that occurred due to long-term gynecological diseases, often latent (chronic oophoritis, salpingitis, ovosalpingitis (Roman *et al.,* 2020).

All the data obtained were recorded in a specially developed accounting form, followed by biometric processing of generalised data and determination of the level of probability according to the Student's t-test.

Experiments conducted on animals do not contradict the current legislation of Ukraine (Article 26 of the Law of Ukraine 5456-VI of 16.10.2012 "On the protection of animals from cruelty") and the "General ethical principles of animal experiments" adopted by the First National Congress on Bioethics (2001) and international bioethical standards (materials of the IV European Convention for the protection of vertebrates used for experimental and other purposes, Strasbourg, 1985) (Festing & Wilkinson, 2007; Simmonds, 2017; Kabene & Baadel, 2019).

RESULTS AND DISCUSSION

The examined group of high-yielding unfertilised cows (n=128) was structured according to the duration of lactation: in the first subgroup there were animals from 50 to 75 days after calving that had not yet been inseminated; in the second and third (76-160 and 161-210 days, respectively) cows that already had a history of 1 to 3 ineffective inseminations, in the third (from 211 to 306 days of lactation) – cows with numerous infertile inseminations. Preliminary vaginal and ultrasound examination of the genitals of these groups of cows did not reveal obvious signs of acute or subacute inflammation of the genitals, but all livestock had clinical signs of damage to mucous membranes by chronic infectious rhinotracheitis-pustular vulvovaginitis of mixed etiology (PVV-IRT). Table 1 shows the dynamics of increasing the number of pathological changes in the ovaries of unfertilised cows with an increase in the lactation period.

Table 1. *Morphological profile of the ovarian status of Holstein cows on day 0 of the induced sexual cycle with different lactation durations, n=128*

Indicators	Lactation period, days			
	50-75	76-160	161-210	211 or more
Number of cows examined, units	24	44	34	26
Average lactation period, days (m±m)	56.63±1.99**	121.52±4.24**	182.82±2.28**	262.27±5.36**
Number of cows with morphofunctional ovarian state on day 0 of the cycle, units	16	26	16	8
%	66.67	59.09	47.06	30.77
Number of cows with detected gonadopathies, units	8	18	18	18
%	33.33	40.91	52.94	69.23

Note: *** – P<0.001*
Source: *compiled by the authors*

If by day 75 after calving, 66.67% of cows had a dominant preovulatory or already ovulating follicle on one of the ovaries on day 0 of the induced sexual cycle, which met the requirements for artificial insemination of the cows, then with each subsequent period the number of animals with the functional state of the ovaries significantly decreased, which is graphically shown in Figure 1. After cows reach 160 lactation days, the ratio of cows with morphofunctional state of ovaries to pathologies becomes critically low.

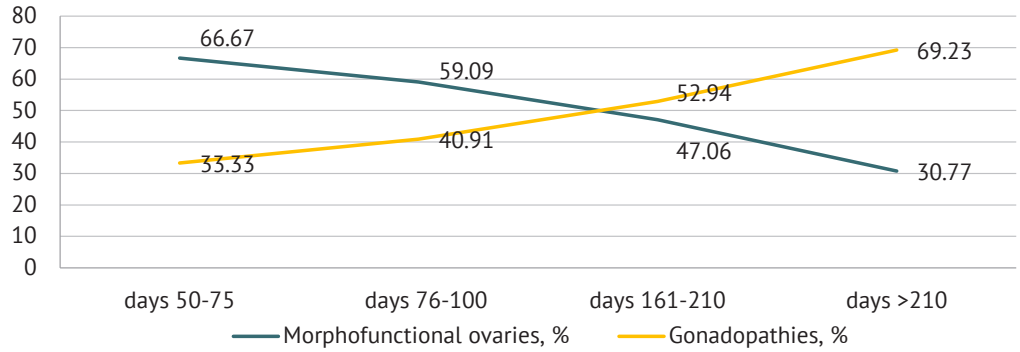

Figure 1. *Effect of increasing the lactation period on the prevalence of ovarian pathologies in high-yielding unfertilised cows, n=128*

The identified situation indicated the need for a more detailed diagnosis of the causes of long-term infertility in highly productive cows that did not have obvious clinical symptoms of gynecological diseases. Differential palpation diagnostics *in vivo* allowed structuring the nature of anatomical and morphological changes in the gonads and palpatory state of the anatomical area "ovary+oviduct" in accordance with the lateral topography, which is shown in Table 2.

***Table 2**. Results of detailed palpation diagnosis of gonadopathies on day 0 of the sexual cycle of high-yielding cows for different lactation periods, n=128*

Indicators	Lactation period, days			
	50-75	76-160	161-210	211 or more
Number of cows examined, units	24	44	34	26
Among them, gonadopathies were detected, units/100%	8	18	18	18
Structured nature of gonadopathies:				
• Bilateral hypogonadism, units	0	6	7	1
%	0.00	33.34	38.89	5.56
• Follicular cystic degenerations, units	8	8	7	11
%	100.00	44.44	38.89	61.11
• Chronic adhesive processes "ovary+oviduct", units	0	4	4	6
%	0.00	22.22*	22.22*	33.33*

***Note:** * – P<0.01*
***Source:** compiled by the authors*

By differential palpation diagnostics of the sexual organs of cows within the anatomical area "ovary+oviduct", cases of irreversible morphological failures in tissues caused by chronic inflammatory adhesive processes with symptoms of chronic oophoritis and ovosalpingitis were established, which were the consequences of prolonged inflammation of the mucous membranes of the reproductive organs, which were usually externally asymptomatic and detected only by ineffective multiple inseminations. Palpation diagnostics of these gynecological pathologies reveal them already in a form unsuitable for rehabilitation of the reproductive function of cows, and other instrumental methods are generally unsuitable for diagnosis *in vivo* (Sidashova *et al.,* 2020). The study showed that with the growth of lactation, the number of detected oophoritis and salpingitis increased from 22.22% to 33.33% with a highly significant correlation for other indicators of gonadopathies (P<0.01). The established trend required timely differential diagnosis of unfertilised cows to prevent sperm production costs for infertile inseminations.

Diagnostic studies have shown that cows with a technologically appropriate lactation term (from 50 to 75 days) among ovarian pathologies had only signs of follicular cysts in the form of large single (rarely double) follicular cysts, anovulatory follicles, or small multiple cystic follicles on one or both ovaries (in 33% of animals, which was presented in detail in the studies (Sidashova *et al.,* 2021). With the extension of the lactation period, cows began to show signs of hypogonadism more often (18%), that is, hypotrophy in the tissues of both ovaries, which is logical, given the amount of nutrients that the lactating animal gives with milk daily. With an growth in the lactation period, there was an increase in signs of cystic degeneration in the ovarian follicular layer (or 42% of 26 animals of the last subgroup, which corresponded to 61.11% of cases of all pathologies in the subgroup) (Fig. 2). Due to the significant influence of paratypical (economic) factors on the level of reproduction of the dairy herd, the indicators of hypogonadism and follicular cysticity among the surveyed livestock did not have a significant correlation (P>0.05).

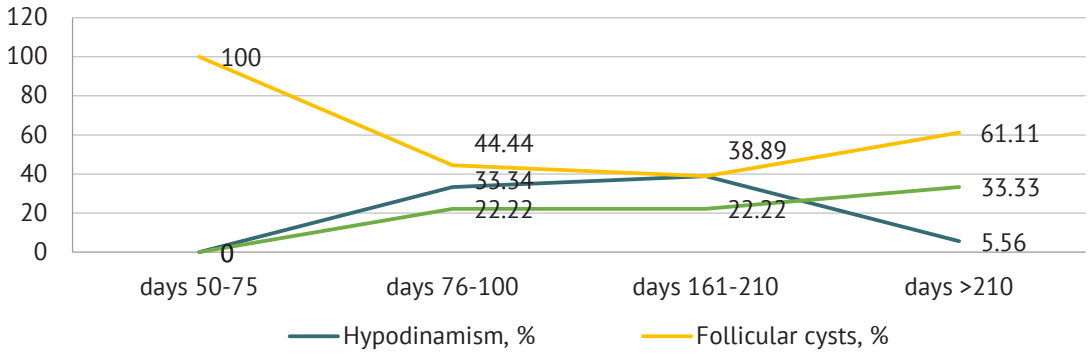

***Figure 2.** Prevalence of ovarian dysfunctions and ovarian pathologies in high-yielding unfertilised cows with different duration of the lactation period, n=62*

Background examination of the biochemical composition of the blood serum of dairy cows of the experimental herd (Table 3) indicated the presence of subclinical signs of metabolic disorders in the body of lactating animals, which are very sensitive to an imbalance of nutrients due to a high level of metabolism and react significantly to a violation of the balance of the internal environment.

Table 3. *Indicators of the biochemical composition of blood serum of high-yielding dairy cows, n=8*

Indicators	Lactation period of more than 40 days	lim		Reference values
		min	max	
Total protein, g/l	74.40±1.17**	72	78	55-75
Albumin, g/l	36.00±0.55**	34	38	30-35.5
Globulin, g/l	38.40±1.36**	34	42	30-35
Protein coefficient, units.	0.94±0.04**	0.9	1.1	0.6-1.1
Urea, mmol/l	6.96±0.41**	6.2	8.5	2.8-5.8
Creatinine, mmol/l	100.00±11.81	86	116	45-140
AAT, u/l	100.00±11.48*	64	127	10-50
ALT, u/l	22.20±4.33*	7	33	10-40
AAT/ALT, units	6.50±2.71**	2.5	17	1.0-3.4
Alkaline phosphotase, u/l	78.06±8.76**	60.4	110.8	20-150
Glucose, mmol/l	2.12±0.06**	2.0	2.3	2.5-4.2
Calcium, mmol/l	1.88±0.04**	1.8	2.0	2.43-3.10
Carotene, mcg%	119.20±5.69*	100	131	275-965
Lipoproteins total, mg%	1,035.40±71.01**	833	1,254	400-800

Note: ** – P<0.01, ** – P<0.001*
Source: *compiled by the authors*

A generalised review of the data of morphometry and pathomorphology of the ovaries of dairy unfertilised cows for different lactation terms demonstrated the existing relationship between the functional or pathological state of the gonads and the content of individual nutrients in the blood serum, and, accordingly, in the daily diet of livestock. Numerous subclinical disorders in the metabolism of dairy cows, according to literature sources, could provoke an exacerbation of gynecological pathologies and dysfunctions of the sexual cycle, which resulted in numerous non-fertile inseminations. At the same time, the duration of the infertile period significantly worsened the morphofunctional characteristics of ovogenesis: in the period up to 75 days after calving, the number of cows with a functional state of ovarian morphology was twice as high as the number of animals with of various gonadopathies of various types, and in the subgroup of cows after 211 days of lactation, on the contrary, the number of cows with gonadal dysfunctions and pathologies was twice as high as the number of animals with a morphofunctional state of ovaries.

The established regularities of the development of ovarian morphogenesis during lactation indicate the need to increase the attention of veterinary medicine doctors to the differential diagnosis of the pathology of the reproductive organs of cows in the first half of lactation, and especially in the postpartum period, which is a resource for increasing the profitability of dairy production.

The reproduction of genetic resources in cattle breeding is based on the biological characteristics of cattle breeding. A retrospective analysis of the literature sources on ovarian morphogenesis has shown that not all aspects of this complex and multifaceted problem are fully revealed. The specifics of the morphological and pathomorphological profile of the ovaries of high-yielding cows on day 0 of the sexual cycle are insufficiently studied.

Thus, there is no consensus on the nature of the topography of physiological ovulation in single or multiple females. All these anatomical and physiological patterns directly affect on reproduction of productive animals. In addition, the likely influence of morphogenesis on the development of ovarian pathologies can be very important in solving issues of reproduction of not only farm animals, but also rare species. The key organs of the reproductive system, namely paired gonads, are the anatomical and physiological basis of technological processes in dairy and meat cattle breeding, so the understanding of ovarian morphogenesis and

ways of its regulation determines the efficiency and the profitability of the livestock.

There is scare information on the influence of functional insufficiency on the intensity and nature of morphofunctional changes in the gonads. The influence of feeding and environmental factors on the biochemical composition of blood in different phases of the sexual cycle, both in normal and gynecological pathology, is not fully disclosed. The differential method used in this study for diagnosing the physiological or pathological state of the ovaries highlights the features of gonad morphogenesis of cows in industrial dairy cattle; the importance of this method is emphasised in data by Borshch *et al.* (2020). Based on the results obtained, differentiation of diagnostic indicators of morphofunctional ovarian structures in cows (n=423) that were synchronised prevented a significant level of ineffective artificial inseminations (pregnancy of experimental cows was 2.1 times higher). Similar results were obtained by Ault (2019).

Researches by Denis-Robichaud *et al.* (2018), indicate the need for monitoring the indicators of automatic sensors of sexual activity detection systems in cows, which increases the number of effective inseminations conducted. In addition, this research expands the methodological database of such studies, which can be implemented in real production conditions.

Studies by Cavallari de Castro *et al.* (2019) and Pascottini (2020) on the impact of chronic or acute and subacute gynecological diseases in lactating cows on fertility indicators emphasise versatile approaches to the diagnosis of pathologies of the reproductive system of cows. Results obtained by Appiah *et al.* (2020) indicate that the above data are debatable, which is explained by the impossibility of creating similar survey conditions at work, which are characterised by a variety of paratypical factors. Probably, the lack of a methodologically developed protocol for comparing indicators of ovarian pathomorphology of cows against the background of their anatomical species polymorphism causes inconsistency in the results of research in different sources.

Nowadays, researchers continue to discuss the main factors that provoke cystic follicle degeneration in dairy cows (Ong *et al.,* 2021), which indicates a lack of knowledge of the phenomenon. At the same time, there are reports in the literature about a steady trend towards an increase in the number of cystic ovarian diseases in cows, but practical experts state that there is no effective scheme for the prevention and therapy of animals with ovarian dysfunction (Nowicki *et al.,* 2017).

Cystic ovarian disease is polyetiological disease and has a common pathology; it is registered in 3.8-6.5% of infertile cows. The frequency of cysts is influenced by a number of factors: breed, stable maintenance, number of calving, duration of previous and stage of current lactation. Thus, ovarian cysts were registered 1.7 times more often in Ayrshire cows (6.5% vs. 3.8%) than in black-and-white cows (Monget *et al.,* 2020).

Based on the conducted experimental studies, it was established that follicular cysts were the most common pathologies of the ovaries. They were registered in 33.33-42.31% of high-yielding cows and positively correlated with the duration of lactation. The results obtained do not differ from the data of Gonzalez Moreno *et al.* (2020).

Bomko *et al.* (2018), Grymak *et al.* (2020) indicate a significant influence on the phenomenon of ovarian dysfunctions of deviations in the optimal ratio of nutrients in the diet, provoking metabolic disorders in various body systems of dairy cows, including hormonal imbalance.

According to Mazur *et al.* (2020), glucogenesis is continuous in ruminants, unlike monogastric animals. Their need for glucose by 90% or more is provided by gluconeogenesis, which occurs mainly in the liver. These processes are actively regulated by the endocrine system, so there is hyperproduction of glucagon, somatotropin, and hypoproduction of insulin. This condition of the endocrine glands enhances lipomobilisation, lipolysis, proteolysis, ketogenesis and contributes to the development of liver dystrophy. With a long and massive intake of lipids in the liver, there is a deficiency of oxaloacetic acid, the source of which is glucose. The concentration of ketone bodies increases in blood serum (ketonuria), urine, and milk, which is expressed by a significant increase of triacylglycerols in the blood of such animals, rapid fat infiltration of haepatocytes and provokes the course of lipomobilisation syndrome, which is characterised by fatty liver dystrophy and other pathologies associated with reduced fertility in highly productive young cows (Malashka *et al.,* 2021).

A decrease in the functional state of the reproductive system during the lactation can also be affected by low levels of calcium (which is important for the contractile activity of the uterus), the content of which was on average 60-70% of the reference values in cows. At the same time, we established that the deficiency of precursors of fat-soluble vitamins had a noticeable negative effect on the secretion of sex hormones in cows.

Based on the experimental data, the carotene content in the blood serum of cows was 2.5-9.0 times less than the need, which was a prerequisite for an increase in the symptoms of ovarian hypotrophy, especially in the middle of lactation (33.34-38.89% of hypogonadism among all detected gonadopathies). The results obtained do not differ from the data of research by Rodriguez *et al.* (2020). Bomko *et al.* (2018) showed that optimising the composition of the diet of dairy of high-yielding cows for a number of ingredients, in particular, Zinc, Manganese, and Cobalt, and improving the balance of the ratio of nutrients in the diet led to an increase in the level of fertility of livestock.

Thus, the study of the morphology and function of the ovaries of cows and heifers remains at the level of comparing the morphometric parameters of the

extracted organs (*in vitro*) or (*in vivo*) using hardware methods (ultrasound scanning) or palpation, which does not allow drawing conclusions about the quantitative and structural patterns of differentiation of generative and hormonal functions of the gonads. All current instructive and methodological guidances are based on generalised and averaged data on the functional activity of the ovaries as a pair of equivalent gonads.

CONCLUSIONS

Studies were conducted *in vivo* to establish morphological and pathomorphological profile of the ovaries of high-yielding cows on day 0 of the sexual cycle to optimise the timing of artificial insemination of cows and reduce economically nonprofitless costs of bull sperm.

Differential palpation diagnostics of high-yielding lactating cows *in vivo* revealed the actual morphological and functional structures of the ovaries on day 0 of the sexual cycle, which was characterised by significant polymorphism, associated both with the specifics of functional morphogenesis of gonads of cows in conditions of industrial keeping (66.67-30.77% of the examined animals) and the presence of reproductive pathology of various etiologies (33.33-69.23% of the studied cows at different lactation periods, respectively).

It was experimentally established that the morphofunctional state of the ovaries on day 0 of the induced sexual cycle of the lactation period, namely: on days 50-75, 66.67% of dairy cows had physiological morphofunctional ovarian structures; and on days 76-160, 161-210, and 211 or more – 59.09%; 47.06%, and 30.77%, respectively ($P<0.001$).

Based on the conducted experiments, it was established that follicular cystic degenerations were the most common pathologies of the ovaries of of high-yielding cows. Signs of ovarian cysts grew with an increase in the lactation term: from 33.33% at the beginning of lactation to 42.31% in the period after 211 days.

Differential palpapatory examination *in vivo* allowed diagnosing an increase in the number of chronic irreversible pathologies in of high-yielding non-inseminated cows in the ovary-oviduct area, manifested by adhesive inflammatory processes in the form of chronic ovosalpingitis ($P<0.05$). An influence of subclinical disorders in the metabolism of high-yielding cows on the development of ovarian dysfunctions was revealed. Identification of the causes and prevention of ovarian dysfunction is a prospect for further study.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

None.

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Морфологічний профіль стану яєчників високопродуктивних корів в 0-й день індукованого статевого циклу

Лілія Григорівна Роман
Кандидат ветеринарних наук, доцент
Одеській державний аграрний університет
65012, вул. Пантелеймонівська, 13, м. Одеса, Україна
https://orcid.org/0000-0002-4983-5418
Микола Володимирович Богач
Доктор ветеринарних наук, професор
Одеська дослідна станція Національного наукового центру
«Інститут експериментальної і клінічної ветеринарної медицини» НААН України
65037, просп. Свободи, 2, м. Одеса, Україна
https://orcid.org/0000-0002-2763-3663
Ніна Іванівна Данкєвіч
Кандидат ветеринарних наук, асистент
Одеській державний аграрний університет
65012, вул. Пантелеймонівська, 13, м. Одеса, Україна
https://orcid.org/0000-0001-8927-5219
Олена Олександрівна Безалтична
Кандидат сільськогосподарських наук, доцент
Одеській державний аграрний університет
65012, вул. Пантелеймонівська, 13, м. Одеса, Україна
https://orcid.org/0000-0002-4257-0699
Євгенія Юрівна Гурко
Асистент
Одеській державний аграрний університет
65012, вул. Пантелеймонівська, 13, м. Одеса, Україна
https://orcid.org/0000-0003-2485-9963

Анотація. Важливою частиною програм управління відтворенням на молочних фермах є виявлення неплідних корів і раннє повторне осіменіння для досягнення вищих показників стільності. Метою дослідження було вивчення особливостей морфогенезу гонад високопродуктивних корів в умовах промислової технології утримання в 0-й день статевого циклу *in vivo* в режимі реального часу. Було використано структурно – порівняльний і статистичний методи, а також біотехнологічну методику пальпаторного циклічного обстеження яєчників з диференційною діагностикою морфофізіологічних або патоморфологічних показників. Результати діагностики яєчників дійних корів (n=128) в 0-й день індукованого циклу, виявленого датчиками крокової активності, показали значний структурний поліморфізм цих органів репродуктивної системи. Встановлено: від 66,67 % до 30,77 % самиць з фізіологічним перебігом фолікулярної фази циклу, тобто в 0-й день на яєчниках преовуляторний фолікул або початок овуляції (за умови зменшеня придатних для запліднення корів за ростом тривалості лактації від 50-75 днів до 211-306 діб (P<0.001). Був діагностований гіпогонадизм у 19,45 % корів, а у 61,11 % – оваріальні дисфункції з проявом кістозних дегенерацій фолікулів; 19,44 % корів на момент дослідження мали незворотні хронічні злипливі процеси тканин статевого тракту у ділянці «яєчник+яйцепровід» (овофорити та овосальпінгіти у латентній формі), що унеможливлювало настання тільності, з вираженою тенденцією росту цієї гонадопатії за збільшення терміну лактації (відповідно: 50-75 діб – 0,00 %; 76-160 діб – 22,22 %; 161-210 діб – 22,22 %; 211 і більше – 33,33 %; P<0.05). Було досліджено тенденцію впливу субклінічних відхилень у метаболізмі корів піддослідного стада на показники біохімічного складу сироватки крові та прояв оваріальних дисфункцій. Отже, було встановлено in vivo морфологічний і патоморфологічний профіль стану яєчників високопродуктивних корів в 0-й день статевого циклу, що дозволило оптимізувати режим штучного осіменіння і зменшити економічно невиправдані витрати сперми. Результати досліджень можуть бути використані в практичній роботі фахівців ветеринарної медицини, наукових співробітників та здобувачів вищої освіти ветеринарного та біологічного профіля

Ключові слова: дійні корови; статевий цикл; яєчники; диференційна пальпаторна діагностика; фолікули; гіпогонадизм; оводисфункції; гонадопатії

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 26(7), 19-33

UDC 618.616-002: 616-093:636.2
DOI: 10.48077/scihor7.2023.19

Mastitis prevention and control: Integration of microbiological and management approaches

Maksim Shevchenko*
Postgraduate Student
Bila Tserkva National Agrarian University
09117, 8/1 Soborna Sq., Bila Tserkva, Ukraine
https://orcid.org/0000-0002-7002-1494
Andrii Andriichuk
PhD in Veterinary Sciences, Associate Professor
Bila Tserkva National Agrarian University
09117, 8/1 Soborna Sq., Bila Tserkva, Ukraine
https://orcid.org/0000-0001-9144-5272
Volodymyr Goncharenko
PhD in Veterinary Sciences, Associate Professor
Bila Tserkva National Agrarian University
09117, 8/1 Soborna Sq., Bila Tserkva, Ukraine
https://orcid.org/0000-0002-7279-6146
Oleksandr Dovhal
PhD in Veterinary Sciences, Associate Professor
Bila Tserkva National Agrarian University
09117, 8/1 Soborna Sq., Bila Tserkva, Ukraine
https://orcid.org/0000-0001-8620-8117

Article's History:
Received: 26.04.2023
Revised: 20.06.2023
Accepted: 12.07.2023

Abstract. Mastitis is a common cause of reduced dairy productivity in cows and poor milk quality. This paper considers a set of approaches based on microbiological studies and risk analysis aimed at reducing the number of cows with mastitis and improving milk quality. The study is aimed at examining microbial agents isolated from the milk of sick cows and means of ensuring udder health, and identifying the main dangers that arise due to errors in the implementation of mastitis prevention measures. The study included microbiological tests of milk, wipes and udder dipping using chromogenic media. For a qualitative risk assessment, a survey of consulting managers and veterinarians was conducted. The paper presents the results of microbiological tests of 115 samples of milk, 45 reusable napkins, and 111 samples of udder dips using conventional and chromogenic media. The most common microorganisms in milk samples were *Streptococcus spp.* 34.4% (*S. agalactiae* and *S. disgalactiae*), *Staphylococcus aureus* 31.1%, and *Escherichia coli* 28.9%. *Staphylococcus aureus* and *Streptococcus spp.* it is associated with infectious mastitis,

Suggested Citation:
Shevchenko, M., Andriichuk, A., Goncharenko, V., & Dovhal, O. (2023). Mastitis prevention and control: Integration of microbiological and management approaches. *Scientific Horizons*, 26(7), 19-33. doi: 10.48077/scihor7.2023.19.

*Corresponding author

and *Escherichia coli* – with sanitary mastitis. To reduce the incidence of mastitis, it is important to apply targeted measures aimed at various categories of pathogens. Udder wipes were contaminated with pathogens associated with the development of mastitis. The use of laundry detergent containing bactericidal components is crucial to minimise contamination of reusable udder wipes. Among the dips under study, 40.6% of the samples had a complete bactericidal effect, and 9.9% had no bactericidal effect. 3 factors of high risk of environmental mastitis and 6 factors of sanitary mastitis were identified. The results of the studies were tested on two dairy farms. Correction of high-risk risk factors led to an increase in the quality of milk in terms of somatic cells and the number of bacteria. The results obtained can be useful for improving the system of prevention and optimisation of mastitis treatment on dairy farms

Keywords: sanitary mastitis; infectious mastitis; mastitis risk; risk analysis; post-milking dipping; mastitis pathogens; milk quality improvement; *Streptococcus spp*.; *Staphylococcus spp*.

INTRODUCTION

Mastitis is the most common mammary gland pathology in cows in all countries, leading to a decrease in animal productivity and the overall economic efficiency of the industry. The development of this disease depends on various factors related to the infectious agent, animal health, the environment, and technological processes. Therefore, accurate and rapid identification of the main pathogens of the disease is important for diagnosis and selection of the optimal prevention and treatment regimen. Identifying the main hazards through risk analysis will help determine the shortcomings of preventive and technological measures on the farm.

Depending on the degree of manifestation of the infectious process, mastitis can be divided into clinical and subclinical. Clinical mastitis is accompanied by the development of pronounced signs of inflammation. Petersson-Wolfe *et al*. (2018) indicate that the pain that occurs, in this case, forms long-term consequences for the animal's health. Subclinical mastitis develops without any visible signs. Martins *et al*. (2020) note that chronic subclinical mastitis leads to a decrease in milk yield and a deterioration in milk quality.

The review by Cobirka *et al*. (2020) summarises the classification of mastitis depending on the causative agents and the degree of clinical manifestation. The researchers indicate that different infectious agents differ in their source of origin, transmission factors, and level of contagiousness. Depending on the pathogen, mastitis is divided into infectious, which has a high potential for transmission from animal to animal, and sanitary, which affects individual animals and has a low potential for transmission.

Milk testing results by Steinberg *et al*. (2022), using 16s RNA gene sequencing, show that the milk microbiota of healthy cows is diverse and variable, and undergoes changes during the development of mastitis. Identification of isolates from the milk of cows with mastitis by Nusrat *et al*. (2021) confirms that the causative agents of mastitis can be numerous genera of gram-positive and gram-negative microorganisms. According to Acharya *et al*. (2021), the genera of microorganisms identified as the main causative agents of mastitis changed during the study period.

Bacterial agents, due to their pathogenicity factors, have a destructive effect on the mammary gland. Thus, Egyedy & Ametaj (2022) note that the innate and acquired immunity of cows play an important role in protecting the mammary gland from mastitis pathogens. In this case, pathogens *Staphylococcus aureus* and *Streptococus uberis* may evade the immune response. A sanitary-associated pathogen *Escherichia coli* is able to multiply in milk without attachment to the epithelium. Authors Blum *et al*. (2020) studied in more detail the pathogenic effects of the sanitary pathogen *Escherichia coli* on the mammary gland. This microorganism, after entering the mammary gland, changes the metabolism in the epithelium and causes immune response processes, which leads to changes in the mammary gland and secretions. These changes may remain after bacterial cleansing of the udder.

Tomazi *et al*. (2018), after studying cases of mastitis in 20 Brazilian dairy farms, found that the risks of the disease are associated with the season of the year and the level of somatic cells in tanker milk. In their review, Girma and Tamir (2022) identified the main risk factors as breed, age, lactation stage, and nipple damage. They also noted the importance of monitoring sick livestock and implementing measures aimed at udder health. Zigo *et al*. (2021), in their systematic review, summarised all factors that may affect the level of occurrence of mastitis and the effectiveness of their treatment. The researchers note that the development of mastitis is a complex process that depends on the pathogen, the condition of the animal, and environmental factors. To effectively combat mastitis, it is necessary to clearly implement preventive measures. In the cross-sectional study with Bayesian network analysis, Horpiencharoen *et al*. (2019) identified clinically important risk factors influencing the occurrence of mastitis. They are associated with pathogens released from milk and animal care measures. However, the level of risk may vary depending on the specific situation. The importance of implementing mastitis management measures was also noted by Stevens *et al*. (2019). In addition, the process of evaluating management approaches increases the level of implementation of recommended measures, and leads to an improvement in the quality of

milk. Diagnostic methods include modern approaches to diagnose mastitis itself, advanced microbiological methods using chromogenic media, molecular genetic methods, and the use of nanotechnology.

Thus, Neculai-Valeanu & Ariton (2022) considered diagnostic tests that can be used for early detection of signs of the disease. The researchers note that the latest methods of non-invasive diagnosis of changes in the clinical condition of the breast can be applied to improve the health of the udder. El-Said & Kamel (2021) point to the possibility of using modern approaches to the diagnosis of mastitis using PCR, microbial gene sequencing, and nanotechnology. Microbiological methods have long been considered the gold standard for identifying mastitis pathogens. They do not lose their relevance even today. Granja *et al.* (2021) established the high sensitivity and specificity of a new, improved medium containing chromogenic components of CHROMagar™ Mastitis to detect the most common pathogens of udder infection.

The purpose of the study was to identify the factors that lead to the spread of mastitis pathogens on the farm, select optimal objects of microbiological analysis and methods for isolating and identifying microorganisms with subsequent risk analysis, and use the results obtained to improve animal welfare.

MATERIALS AND METHODS

The research was conducted in the research laboratory of the Department of veterinary and sanitary expertise and laboratory diagnostics of the Institute of Postgraduate Training of Heads and Specialists of Veterinary Medicine of Bila Tserkva NAU. Samples of milk from sick animals, napkins and udder dips were taken in the period May 2021-May 2022. The survey of consulting managers and veterinarians was conducted in June-July 2022. Visits to farms for experimental testing of the results obtained took place in the fall of 2022.

Milk sampling. Milk samples were taken during the cows' stay in the milking parlour. First, the udder skin was cleaned of dirt and debris with a disposable cloth soaked in alcohol to disinfect the skin and reduce the risk of contamination. A separate napkin and vessel were used for each nipple. The first jets of milk were milked and disposed of. Milk samples were taken separately from each udder lobe in a single-use individual sterile cup and immediately sent to the laboratory. 115 milk samples taken from 27 subclinically and 63 clinically sick animals were examined.

Microbiological studies of milk using non-selective and selective media. Milk samples were cultured on the blood agar (Conda) with the addition of 5% sheep red blood cells (Pharmstandard Biolek, Ukraine) and MacCONKEY Agar (Merc) at 37°C for 24-48 hours. Colonial characteristics and hemolysis were determined, gram-stained, and morphological characteristics of microorganisms were determined. Gram-positive cocci were tested with catalase and differentiated into positive and negative coagulase activity. Cocci catalase-positive colonies were then cultured in the Staph Api 20 kit. Coccoid catalase-negative colonies were studied using Hydrolysis of esculin, fermentation of hippurate and inulin, and growth in NaCl were determined using the CAMP test. For gram-negative bacteria, oxidase, indole formation, Voges Proskauer reaction, Lysine Decarboxylase test fermentation of glucose, lactose, mannitol, maltose, sucrose, urease, and citrate were used (Tarazona-Manrique *et al.,* 2019).

Microbiological studies using chromogenic media. 2 chromogenic media were used CHROMagar™ Orientation and CHROMagar™ Mastitis (CHROMagar, France). The growth pattern was determined visually.

CHROMagar™ Mastitis consists of 2 separate media for gram-positive bacteria (Mastitis GP) and gram-negative (Mastitis GN) bacteria. The growth of gram(-) bacteria is inhibited on Mastitis GP medium, and the growth of gram(+) bacteria is inhibited on Mastitis GN medium. CHROMagar™ Orientation is one-component, so it requires additional gram staining of smears taken from colonies. Differentiation of colonies occurs by analysing the colour in which they are coloured as a result of growth (Table 1).

For inoculation, five-fold serial dilutions were made, and native material and 0.1 ml of suspension were plated with dilution from 10^{-2} up to 10^{-5}. The cultures were cultivated for 24-48 hours at 37°C, after which the colonial morphology were analysed and their number was counted.

Table 1. *Colouration of microbial colonies grown on chromogenic media*

Microorganism	CHROMagar™ Orientation	CHROMagar™ Mastitis
Gram(-) bacterial		
Esherihia coli	dark pink to reddish	dark pink to reddish
Klebsiella spp., Enterobacter spp., Citrobacter spp., Serratia spp. (KECS group)	metallic blue (+/- reddish halo)	metallic blue (+/- reddish halo)
Proteus spp., Morganella spp.,Providencia spp.	brown halo	brown halo
Proteus vulgaris	blue with brown halo	
Pseudomonas spp.	Translucent (+/- natural pigmentation cream to green)	translucent (+/- natural pigmentation cream to green)
Acinetobacter spp.	cream	Variable

Table 1, Continued

Microorganism	CHROMagar™ Orientation	CHROMagar™ Mastitis
Stenotrophomonas spp.	colourless	Variable
Gram(+) bacterial		
*Streptococcus agalacti*ae	light blue	turquoise blue
Streptococcus uberis		metallic blue
Enterococcus spp.	turquoise blue	Variable
Staphylococcus aureus	golden, opaque, small	pink
Staphylococcus epidermidis	cream, pinpoint colonies	variable
Staphylococcus saprophyticus	pink, opaque, small	variable
Yeasts		
Candida albicans	cream, pinpoint colonies	cream, pinpoint colonies

Source: *compiled by the authors based on CHROMagar™ Mastitis Instructions For Use (n.d.) and CHROMagar™ Orientation Instructions for Use (n.d.)*

Sampling to determine the contaminating agent of napkins. A cut-off part of the napkin with sides of 10×10 cm was sent for the study. Sterile disposable gloves were worn and a sterile instrument was used before taking the sample. The cut material was placed in a sterile container. After washing according to the procedure performed on the farm, another area was re-cut off in the same napkin and placed in another sterile dish. After entering the laboratory, a piece of napkin was filled with 100 ml of sterile saline solution for 5 minutes. After exposure, the napkin was pressed against the wall of the test tube using sterile tweezers. To determine the contaminating agent, a bacterial suspension was inoculated in the media indicated above.

45 napkins were analysed. Of these, 29 were washed in a washing machine at a temperature of 60°C using domestic detergent, and another 16 – in a washing machine at a temperature of 60°C using a special detergent containing a bactericidal component.

Determination of the bactericidal activity of udder dipping. Museum strains were used to determine the antibacterial properties of dipping as control bacteria *Escherichia coli* ATCC 25922 and *Staphylococcus aureus* ATCC 25923, as well as microorganisms isolated from the studied samples from farms. 111 dip samples were examined.

Microbial strains were transplanted from the storage medium to trypsin-soy agar (Conda) and cultivated for 24-48 hours at 37°C. A bacterial suspension with a bacterial cell concentration of 1.5×10^8 CFU/ml was prepared from the pure culture. To simulate a clean skin surface, the experiment used a mixing suspension consisting of a 1.5% solution of bovine albumin diluted in saline. A mixture of sodium thiosulphate, 3 g/l to 20 g/l + polysorbate 80, 30 g/l + lecithin, 3 g/l was used to neutralise the active ingredients of the dips. To prepare mixture-1, 0.1 ml of bacterial suspension and 0.2 ml of mixing suspension were added to the test tube, mixed in an ice bath for 2 minutes at 0°C, and 9.7 ml of the test dip was added and kept for 60 seconds and 5 minutes at room temperature. After that, 1 ml of the resulting mixture-1 was transferred to a second tube containing 8 ml of neutralising suspension and 1 ml of water. The mixture-2 was kept in a water bath for 5 minutes at 20°C. After holding, 1 ml of mixture-2 was taken twice and placed in separate Petri dishes, and 15-20 ml of molten TCA was poured at a temperature of 45°C±1°C, and kept in a thermostat for 24-48 hours at 37°C.

Additionally, a decimal dilution was prepared, 0.5 ml of mixture-2 was added to 4.5 ml of neutralising agent, pipetted and sown with 1 ml of the resulting dilution, previously indicated by the method, on 2 agar plates. Additionally, a negative control was set, where sterile water was added instead of dip. The media were cultured during the day and the number of colonies formed was calculated, the criteria for evaluating bactericidal activity are shown in Table 2.

The bacterial load was determined by the equation:

$$N = \Sigma a / V(n1 + 0.1n2)d$$

where Σa – sum of colonies on cups selected for counting; V – volume of inoculate that was introduced into each cup, cm^3; $n1$ – number of cups of the first dilution selected for counting; $n2$ – number of cups of the second dilution selected for counting; d – degree of dilution (first) for which counting is performed.

Table 2. *Level of bactericidal action of the udder dipping depending on the growth of the microorganisms*

Level of bactericidal action of udder dipping	Growth characteristics
Full bactericidal effect	No growth
Incomplete bactericidal effect	1-99 CFU/ml
Subactericidal effect	100-299 CFU/ml

Source: *compiled by the authors*

Development of a matrix for assessing the risks associated with flaws at the milking stage. The survey of consulting managers was conducted by e-mail. 12 experts were interviewed. For the survey, 15 questions were formulated that correspond to the factors entered in the risk assessment matrix. A question was asked for each expert:

How do you assess the impact of *factor n* on the risk of mastitis?

Evaluation criteria: low impact, medium impact, significant impact.

The survey of doctors was conducted using paper questionnaires. 27 doctors took part in the survey. The factors described in the study were divided into two groups: 1 – violation of milking technology; 2 – laboratory tests conducted on the farm.

The question were formulated as follows:

How often have you detected violations of milking technology *n*?

Evaluation criteria: rarely, often, very often.

How often do you conduct research *x*?

Evaluation criteria: we never do it, sometimes we do it, and we do it all the time.

The survey questionnaire is available on request.

As a result, a matrix of qualitative risk assessment was developed. The vertical axis of the Matrix indicates the probability of detecting a factor on the farm, and the horizontal axis indicates the level of influence of the factor. The degree of danger of each factor can be determined according to the probability of manifestation and the level of exposure. The survey was anonymous, and the authors of the study did not receive or store the personal data of respondents.

Analysis of the causes of deterioration in milk quality. Two dairy farms with deteriorating milk quality in terms of somatic cells and bacterial load were selected for experimental testing of the effectiveness of corrective measures. During the first visit to the farm, the general sanitary condition of the farm, the quality of cow maintenance, and the system of grouping and keeping sick animals and cows of various technological groups were evaluated. Then the milking process was monitored. All lactating livestock were examined using a California test. The number of somatic cells was counted in milk from the affected animals and the infectious agent was identified. At each farm, flushes from milking cups, udder care products, and disinfectant samples were taken for microbiological studies.

Based on the results, farms were offered measures to reduce the impact of risk factors according to the risk analysis matrix. The effectiveness of the implemented measures was monitored based on weekly studies of tanker milk.

Statistical analysis. The analysis of experimental studies was carried out using the Microsoft Excel 2020 software suite. The results of the study were statistically calculated using a direct method for determining the standard deviation.

Experimental studies were conducted in accordance with modern methodological approaches and in compliance with the relevant requirements and standards, in particular, they meet the requirements of DSTU ISO/IEC 17025:2005 (2006). All manipulations were performed in accordance with the European Convention for the protection of vertebrates used for experimental and other scientific purposes (European Convention, 1986). The survey was conducted according to the International Compilation of Human Research Standards (2021).

RESULTS

Monoinfection was identified in 68 (75.6%) cows, and an association of 2 or more pathogens was found in 22 (24.4%) cows (Table 3).

Table 3. *Bacterial cultures found in the tested milk*

Pathogens isolated	Subclinical mastitis n=27	%	Clinical mastitis n=63	%	Total n=115	%
Staphylococcus aureus	4	14.8	9	14.3	13	14.4%
Staphylococcus epidermididis	2	7.4	4	6.3	6	6.7%
Staphylococus saprofiticus	1	3.7	3	4.8	4	4.4%
Streptococcus agalactiae	4	14.8	9	14.3	13	14.4%
Streptococcus disgalactiae	1	3.7	5	7.9	6	6.7%
Streptococus uberis	2	7.4	2	3.2	4	4.4%
Escherichia coli	5	18.5	11	17.5	16	17.8%
Klebsiella pneumoniae	0	0.0	6	9.5	6	6.7%
Staphylococcus aureus + Escherichia coli	1	3.7	6	9.5	7	7.8%
Staphylococcus aureus + Streptococcus agalactiae	2	7.4	0	0.0	2	2.2%

Table 3, Continued

Pathogens isolated	Subclinical mastitis n=27	%	Clinical mastitis n=63	%	Total n=115	%
Staphylococcus saprofiticus + Streptococcus disgalactiae	2	7.4	1	1.6	3	3.3%
Staphylococcus epidermididis + Staphylococcus aureus		0.0	2	3.2	2	2.2%
Staphylococcus aureus + Streptococcus disgalactiae	2	7.4	4	6.3	6	6.7%
Staphylococcus epidermididis + Escherichia coli + Streptococcus agalactiae	1	3.7	1	1.6	2	2.2%
Total	27	100.0	63	100.0	90	100.0

Source: *compiled by the authors*

Staphylococcus aureus was identified in 33.3% of cows with clinical and 30.1% with subclinical mastitis. *Staphylococcus epidermididis* was isolated in 11.1% of both animal groups. *Staphylococus saprofiticus* was detected in 11.1% of subclinically sick animals and 6.4% of clinically sick animals. *Streptococcus agalactiae* and *Streptococcus disgalactiae* more often isolated in subclinically sick animals – 25.9% and 18.5%, respectively, while the detection rate in clinically sick animals was 15.9%. *Streptococus uberis* was isolated from 7.4% of subclinically sick and 3.2% of clinically sick animals. *Escherichia coli* were present in 28.6% of clinically and 25.9% of subclinically sick animals. *Klebsiella pneumoniae* was isolated only as a monoculture in 6.6% of clinically sick animals.

To keep reusable udder treatment wipes clean, they need to be washed systematically. The level of contamination of napkins with microorganisms after washing with domestic detergent differed from that for washing with a special detergent containing bactericidal components (Table 4).

Table 4. *Number of contaminated wipes with each pathogen before and after washing*

Pathogen	Before washing with domestic detergent n=29	After washing with domestic detergent n=29	Before washing with antibacterial detergent n=16	After washing with antibacterial detergent n=16
Staphylococcus aureus	26	18	15	3
Staphylococcus coagulase negative	29	27	16	8
Streptococcus spp.	16	9	1	0
Escherichia coli	29	12	8	2
Klebsiella spp.	9	3	0	0
Pseudomonas spp.	11	6	6	1
Bacillus spp.	26	14	14	6
Proteus spp.	24	16	12	3
Candida spp.	25	16	9	2

Source: *compiled by the authors*

After washing with domestic detergent, the number of napkins that are contaminated with *Staphylococcus aureus* decreased by 31.6%, *coagulase negative Staphylococcus* by 6.9%, *Streptococcus spp.* by 43.7%, *Escherichia spp*. by 58.6%, *Klebsiella spp.* by 66.7%, *Pseudomonas spp.* by 45.5%, *Bacillus spp.* by 46.2%, *Proteus spp.* by 33.3%, and *Candida spp.* by 36%. After washing with a detergent containing bactericidal components, the number of napkins that are contaminated *Staphylococcus aureus* decreased by 80%, *coagulase negative Staphylococcus* by 50%, *Streptococcus spp.* by 100%, *Escherichia spp.* by 75%, *Klebsiella spp.* by 100%, *Pseudomonas spp.*by 83.3%, *Bacillus spp.* by 57.1%, *Proteus spp.* by 75%, and *Candida spp.* by 78.6%. None of the washing methods ensured the sterility of the napkins. Washing with a detergent containing bactericidal components led to a reduction in the level of contamination with various pathogens from 50 to 100% (by an average of 74.8%). Washing with domestic detergent resulted in a reduction in contamination from 6.9 to 66.7% (an average of 40.8%).

According to the results of dip studies, it was found that 40.6% of the studied samples had a complete bactericidal effect, 49.5% – incomplete bactericidal effect, and 9.9% had no bactericidal effect actions. 6.3% of all dips under study were contaminated (Table 5).

Table 5. *Bactericidal activity of dips depending on the active substance*

Active ingredient	Full bactericidal effect	Incomplete bactericidal effect	Subactericidal effect/of them contaminated
Iodine n=45	22	20	3/1
Lactic acid n=17	7	9	1/1
Chlorhexidine n=49	16	26	7/5
Total	45	55	11/7

Source: *compiled by the authors*

Dips which include the active substance iodine showed a complete bactericidal effect in 48.9% of cases, there was no bactericidal effect in 6.7% of the studied samples. Dips with lactic acid showed a complete bactericidal effect in 41.2% of cases, and 5.9% had no effect. However, the smallest number of samples were tested with this substance. The most frequent absence of bactericidal effect was found in dips with chlorhexedine – 14.3% of samples. 32.7% of the samples showed a complete bactericidal effect, which is the lowest indicator among all the samples under study. Of the 11 dips with no bactericidal action, 7 (63.6%) were contaminated. *Bacillus spp*. bacteria were identified in iodine-containing dips, and 3 – in chlorhexidine-containing dips. *Aspergillus spp*. fungi contaminated one dip with lactic acid and 2 dips with chlorhexidine.

According to the results of a survey of specialists, 16 risk factors that arise as a result of a violation of milking technology were identified, and the level of danger associated with them was determined. 3 factors had a high risk of developing mastitis caused by sanitary pathogens, medium – 9 factors, and low – 4 factors (Fig. 1). For pathogens of infectious mastitis, the number of factors for each risk group is 6, 5, and 5, respectively (Fig. 2).

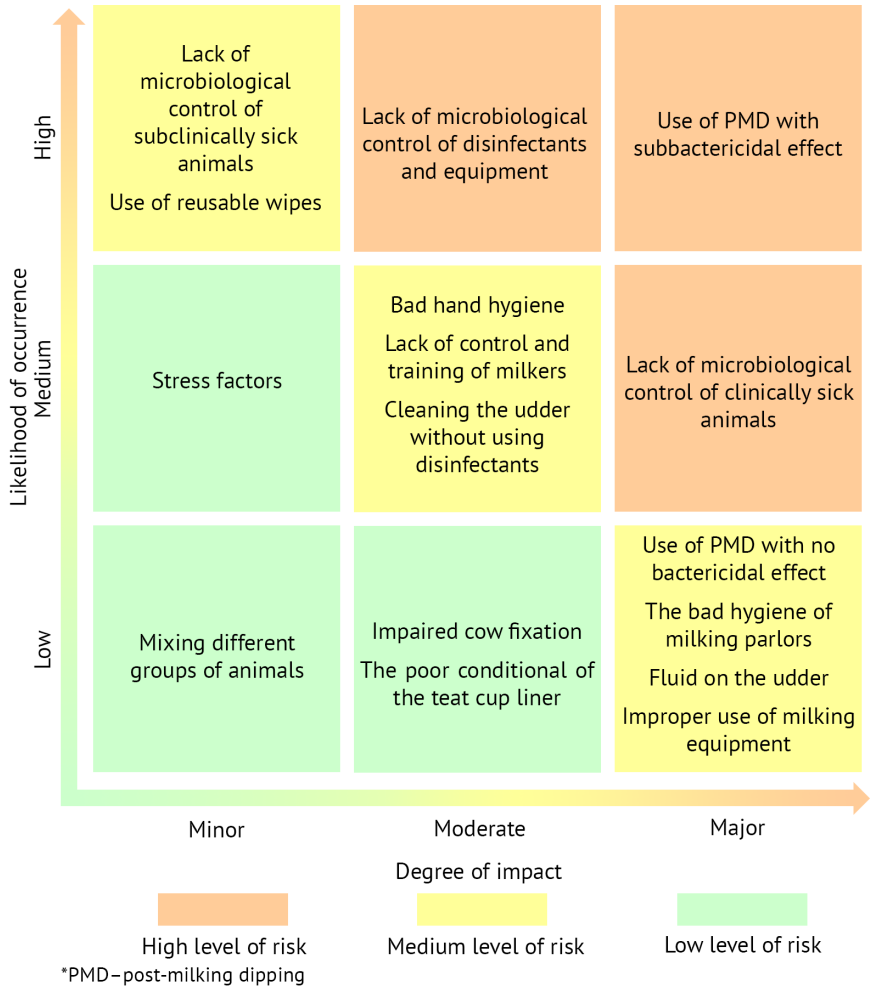

Figure 1. *Matrix of the risk level of sanitary mastitis*

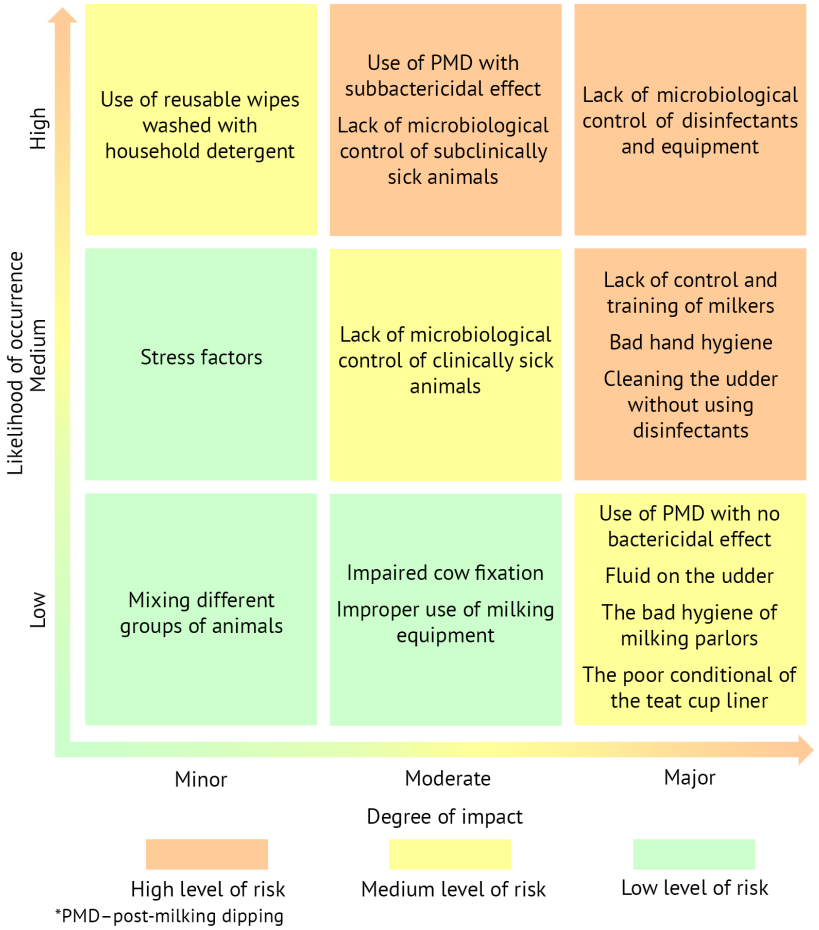

Figure 2. *Matrix of the risk level of infectious mastitis*

The developed risk matrix was tested to improve milk quality on two farms. Chromogenic media were used to accelerate the results of microbiological analysis (Fig. 3). The use of chromogenic media allowed identifying most of the pathogens of mastitis already in the first culture. This accelerated the identification of the main group of microorganisms that cause intramammary infection at each farm, and reduced the time required to select the correct corrective measures.

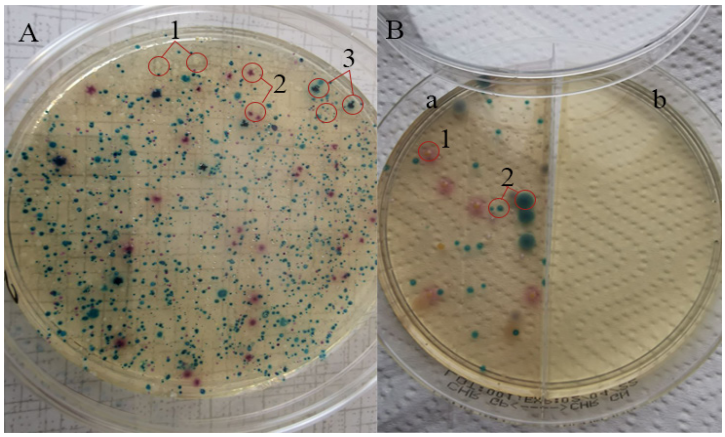

Figure 3. *Bacterial growth on chromogenic media*
A) CHROMagar™ Orientation 1. Staphylococcus epidermidis – cream, pinpoint colonies, 2. Staphylococcus saprophyticus – pink, opaque, small, 3. Streptococcus agalactiae – light blue B) a. Mastitis (GP) – 1. Staphylococcus aureus – pink 2. Streptococcus agalactiae – turquoise blue b. Mastitis (GN) – no growth

At the time of the study, 10 clinically sick animals and 17 subclinically sick animals were identified on the first farm. There are 7 clinically sick and 12 subclinically sick animals on the second farm (Table 6).

Table 6. *Data on livestock and milk quality at the beginning of the study*

	Number of livestock	Cows with mastitis	Bacterial load, thous. CFU/cm³	Somatic cells thous./cm³
Farm 1	970	27 (2.8%)	102	210
Farm 2	430	19 (4.5%)	145	275

Source: *compiled by the authors*

On Farm 1, the number of somatic cells in the mammary secretion ranged from 26.5 to 456.1×10⁴/cm³ (average 111.7±125.6×10⁴/cm³), on Farm 2 – from 32.2 to 567.6×10⁴/cm³ (average 111.7±125.6×10⁴/cm³). Animals from Farm 1 were found to have *Streptococcus agalactiae*, *Staphylococcus saprophyticus*, *Staphylococcus epidermidis*, *Esherihia coli*, and *Staphylococcus aureus*. In animals from Farm 2 – *Streptococcus disgalactiae*, *Staphylococcus epidermidis*, *Esherihia coli*, and *Staphylococcus aureus* (Table 7).

Table 7. *Results of milk tests from subclinically sick animals*

	Farm 1 n=30			Farm 2 n=17		
	Mean±SD, CFU×10⁴/cm³	Min, CFU×10⁴/cm³	Max, CFU×10⁴/cm³	Mean±SD, CFU×10⁴/cm³	Min, CFU×10⁴/cm³	Max, CFU×10⁴/cm³
Streptococcus agalactia	14.9±18.9	0.13	60	-	-	-
Streptococcus dysgalactiae	-	-	-	14.3±11	7	27
Staphylococcus saprophyticus	1.4±0.7	0.6	1.8	-	-	-
Staphylococcus epidermidis	1.3±1.5	0.16	4.5	14.2±18.2	1.3	27
E. coli	1±1.1	0.15	3	2.9±2.7	0.7	6.8
Staphylococcus aureus	0.4±0.19	0.39	0.56	6.5±7.1	1.1.	19

Source: *compiled by the authors*

It was established that both farms had good sanitary condition of the premises and balanced feeding. Factors leading to an increased risk of mastitis were identified at the milking stage (Table 8). These conclusions were also supported by the results of laboratory studies, the dominant microflora was pathogens associated with the development of subclinical mastitis.

Table 8. *Results of risk analysis on experimental farms*

Risk level	Farm 1	Farm 2
High level of risk	Lack of microbiological control of disinfectants and equipment Use of PMD with subbactericidal action Lack of a system for monitoring milkers' knowledge Lack of microbiological control of subclinically sick animals	Lack of microbiological control of disinfectants and equipment Udder cleaning without using disinfectants
Average level of risk	Poor hand hygiene of staff Use of reusable wipes washed with domestic detergent	Use of reusable wipes washed with domestic detergent
Results of analysis of post-milking dipping	Udder dipping had an incomplete bactericidal effect	Udder dipping had a full bactericidal effect
Results of equipment analysis	Bacteria of the genera *Str. agalactiae, Staph. aegeis*, *Esherihia coli* and groups *KECS* on three milk glasses	Bacteria of the genera *Str. dysgalactiae*, *Staph. aegeis*, *Esherihia coli* and groups *KECS* on five milk glasses

Source: *compiled by the authors*

Based on the results, it was recommended to immediately apply measures to correct factors that create a high risk of mastitis.

At Farm 1, the udder dipping with lactic acid showed an incomplete bactericidal effect, it was recommended to replace it with another one with iodine. The use of udder dips based on chlorhexidine and the use of disposable wipes was introduced. The staff was instructed on the use of pre- and post-milking dipping, and the patterns of spread of bacterial pathogens of infections and their role in the occurrence of mastitis was explained. Relevant educational and visualisation materials were provided.

At Farm 2, the use of pre-milking dipping based on hydrogen peroxide, additional treatment of the udder before milking with a disinfectant based on peracetic acid and hydrogen peroxide by aerosol method, and wiping the udder dry with disposable paper towels were introduced. In both farms, it is recommended to replace all rubber due to its condition (the presence of microcracks, loss of elasticity). When re-examined, the dipping had a complete bactericidal effect, and the new rubber on the milk cups was not contaminated. The number of mastitis cases on Farm 1 decreased to 18 of them 7 are subclinical, on Farm 2 – the number decreased to 12 of which 5 are subclinical (Table 9)

Table 9. *Data on livestock and milk quality at the end of the study*

	Number of livestock	Mastitis	Bacterial load, thous. CFU/cm³	Somatic cells, thous./cm³
Farm 1	970	18 (1.9%)	68	154
Farm 2	430	12 (2.8%)	102	145

Source: *compiled by the authors*

A week after the proposed interventions, the total number of bacteria and the number of somatic cells in tanker milk began to decrease (Fig. 4). Indicators of bacterial load decreased faster than indicators of somatic cells. However, at the time of the study, milk on two farms met the requirements for the "Extra" grade in terms of somatic cell indicators. While in terms of bacterial load, milk corresponded to the "Highest" grade.

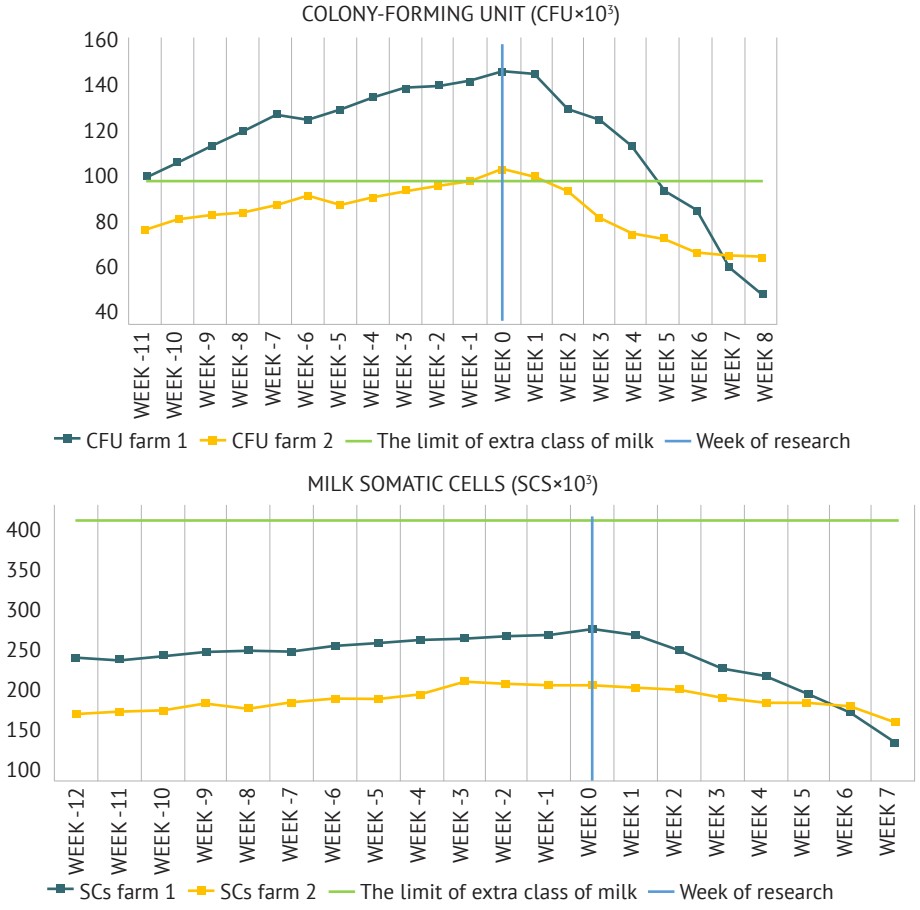

Figure 4. *Dynamics of changes in bacterial load indicators (CFU) and somatic cells (SCS)*

Recommendations for the two farms differed due to research results and specific factors that led to an increased risk of mastitis in each farm. Another important condition was the economic viability of farms to implement risk correction measures. As a result of the measures implemented on Farm 1, milk corresponded to the "Extra" grade two weeks after the implementation of the measures. More violations were detected on Farm 2, and milk quality improved in the fifth week after the recommendations were implemented.

In the study of milk from sick animals, pathogens associated with infectious mastitis *Staph. aureus*, *Str. Agalactiae*, and *Str. disgalactiae* were more often detected. On the visited dairy farms, this trend continued. But this may be conditioned by the choice of farms for research. Dips with incomplete bactericidal action were also used on one of the farms under study. This is consistent with previous data from studies of the bactericidal activity of udder dipping. Correction of the factors indicated in the risk analysis matrix contributed to an improvement in milk quality on farms where the dominant infectious agents were pathogens associated with the infectious mastitis.

DISCUSSION

The paper by Elias *et al.* (2020) described three infectious agents isolated from milk selected from Ukrainian farms. Among all pathogens isolated from cow's milk, *E. Coli* was identified in 23.3%, *S. aureus* – in 13%, *Str. agalactiae* – in 11% of isolates. The data obtained differ from the results of the present study, which may be conditioned by the analysis of a larger number of samples and the percentage of samples from clinically and subclinically sick animals.

In a study by Kenyan scientists Mbindyo *et al.* (2020), the main causative agent of subclinical and clinical mastitis was coagulase-negative staphylococci. Bacteria *Streptococcus spp.* – the second most common pathogen that caused clinical infections more often. The third most common pathogen, *S. aureus*, was more often isolated from the milk of subclinically sick animals. *E. coli* was isolated quite rarely, more often from the milk of clinically sick animals. Study of milk microflora using MALDI-TOF MS performed by Nonnemann *et al.* (2019) found that the most common pathogen in the biomaterial was *Streptococcus spp., S. aureus* and *E. coli*. Pascu *et al.* (2022) also found that the most common causative agent of mastitis in Romania was *S. aureus* bacteria. At the same time, *Staphylococcus spp.* and *Streptococcus spp.* are more often isolated from cows with subclinical mastitis, and *E. coli* – from clinically sick cows. In this study, there were similar trends in the distribution of major pathogens at the birth level, although the frequency of isolation of specific pathogens differed.

Several different authors (Horpiencharoen *et al.*, 2019; Ndahetuye *et al.*, 2020; Tomazi *et al.*, 2018) conducted statistical studies of the influence of various factors on the risks of mastitis. They paid attention to environmental factors, farm conditions, technological processes, pathogens, and animals in order to identify statistically significant correlations with the level of mastitis occurrence. The present study analysed aspects directly related to violations of milking technology, and the risk assessment was based on qualitative indicators. This approach may be more understandable for practitioners and farm owners.

Mistakes in preparing the udder for milking are associated with improper use of disinfectants and wipes. Often, farms used reusable wipes washed with domestic laundry powder, or did not use disinfectants to treat the udder. These factors have a stronger impact on the risk of infectious mastitis. Instead of disinfectants, some farms use running water, which leads to the washing of bacteria from the entire surface of the udder to the opening of the milk canal and their entry into the middle of the mammary gland. Dips are also available on the market to treat the udder before milking. Rowe *et al.* (2018) have concluded that pre-milking udder dipping has little effect on the development of clinical mastitis. Therefore, there is no need to apply protocols using these drugs in routine practice. Gleeson *et al.* (2018) also came to similar conclusions, but they note that the use of pre-milking dipping may be useful for herds with a high number of subclinically sick livestock.

Another mistake identified by this study, which does not happen often and significantly increases the risk of mastitis, is poor hand hygiene of personnel. Ndahetuye *et al.* (2020) note that washing staff's hands without using disinfectants increases the risk of mastitis caused by non-golden staphylococci.

At the milking stage, violations were identified related to incorrect use of milking equipment (incorrect dressing of milk glasses, exceeding the milking time), fixing animals and creating stressful factors. Odorčić *et al.* (2019) drew attention to the importance of proper milking equipment settings to reduce the number of mastitis cases. While the animal is in the milking parlour, the risk of infection can be reduced by other sanitary and technological measures, so the impact on the occurrence of infectious mastitis, in this case, is average. Since the nipple remains open, pathogens from the environment can get to it, so the risk of developing sanitary mastitis is high. Melvin *et al.* (2019), using ultrasound, found that the nipple canal remains open for some time after milking. But they noted that more research is needed to identify links between the size of the nipple canal diameter and the risk of udder infection.

On some farms, insufficient attention was paid to the condition of the milking rubber. This factor has an average effect on the risks of sanitary mastitis and a very strong effect on infectious mastitis. After exceeding the service life, the rubber loses its elasticity, microcracks form on its surface, where milk residues and bacteria that form a biofilm accumulate. In this case,

the disinfectants used to clean the equipment will be less effective. Latorre Data *et al.* (2020) indicate that biofilm formation on dairy equipment plays a role in the epidemiology of mastitis caused by *S. aureus*.

To protect the nipple canal after milking, post-milking dipping with bactericidal components is used. According to Lopez and Hillerton (2018), modern udder treatments not only create a physical barrier in the form of a film around the nipple opening. They also have a positive effect on the general condition of the nipple, which reduces the risk of mastitis. According to the study, a large number of such drugs have a subbactericidal effect. This is not an obvious problem for the farm owner, so it will not be fixed in time. This factor significantly increases the risk of sanitary mastitis, and has an average effect on the risk of infectious mastitis. Some dips may not have a bactericidal effect at all, the probability of this is not high, but in this case, the risk of mastitis increases significantly. As noted by Hohmann *et al.* (2020) the use of post-milking dipping has a long-term bactericidal effect on coliform bacteria and *S. aureus,* which can get on the skin of the nipple of healthy animals and are the main causative agents of mastitis. The bactericidal activity of dipping was studied in those farms where a large number of mastitis or a tendency to their growth were detected. Therefore, these data should be considered in the context of risks that may arise on the farm, and not for the analysis of the quality of goods available on the market.

Training of new personnel takes place in all farms and is part of the technological process. However, farms often lack periodic monitoring of personnel knowledge. Personnel who are not subject to control measures are not able to independently assess their wrong actions. Weak skills of milkers significantly increase the risk of infectious mastitis, and have less impact on the risk of sanitary mastitis. Rarely, farms may have a poor sanitary condition of pre-milking facilities, but this has a significant impact on the occurrence of sanitary mastitis. Bhakat *et al.* (2020) draw attention to the fact that in order to implement modern mastitis control strategies, it is necessary to provide training for farm owners. Alanis *et al.* (2022) also note the importance of training milkers. The introduction of an online training system has increased staff awareness of milking equipment failures and udder health assessment. Both authors note the importance of providing infrastructure for training and educational materials.

Without conducting bacteriological analyses, it is impossible to determine the risks of mastitis and use the risk analysis matrix developed by the study. Farms often showed a lack of microbiological control of subclinically ill animals. This significantly increases the risk of infectious mastitis, but has less effect on the risk of sanitary mastitis. Very often farms lack microbiological control of equipment and disinfectants, which has a significant impact on the risk of both groups of mastitis. Microbiological studies of clinically ill animals are often carried out on farms. Data obtained by Firth *et al.* (2019) show that microbiological studies are conducted more frequently on farms that are not affected by mastitis.

Identification of the source of danger and the nature of the infectious agent is extremely important for effective control of the pathogen. As this study has shown, performing microbiological control is also necessary to determine the effectiveness of disinfectants.

CONCLUSIONS

The most frequently detected infection-associated pathogens in milk from cows with mastitis were *Staphylococcus aureus* 33.3%, *Escherichia coli* 28.9%, and *Streptococcus agalactiae* 18.8%. *Escherichia coli* was more often identified with monoinfection, *Staphylococcus aureus* – with polyinfections.

Reusable wipes that are used to wipe the udder were contaminated with microorganisms that can become pathogens of mastitis. Washing with a detergent containing a bactericidal component significantly reduced the level of bacterial load compared to domestic laundry powder.

Most of the 49.5% of the udder dipping samples showed incomplete bactericidal action, 40.6% had a complete bactericidal effect, and 9.9% had a subbactericidal effect. Udder dips containing the active ingredient iodine had the best results. In the absence of microbiological monitoring and a system for assessing the skills of personnel, the risk of mastitis significantly increased. Priority correction of these factors will lead to an improvement in milk quality and a reduction in the level of infectious mastitis.

Measures, according to the risk analysis matrix on farms with milking technology violations, contributed to improving the quality of milk within a few weeks after their introduction. Microbiological studies allowed identifying the causative agents of mastitis, establishing contamination of care products, and determining the effectiveness of disinfectants. These data are necessary to determine the risks associated with various infectious agents.

To increase the effectiveness of the proposed risk analysis matrix, more research is needed on the correlation between risk factors and the level of mastitis in the herd. Along with the microbiological methods used in the research, the analysis of the possibility of using molecular genetic methods is promising.

ACKNOWLEDGEMENTS

The authors would like to take this opportunity to express their sincere gratitude to “VKF Polyus” LLC for its assistance in collecting materials and communicating with experts and veterinarians. The authors are grateful to “SANIMED-M” LLC for its advisory support and assistance in conducting microbiological research.

CONFLICT OF INTEREST

None.

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Профілактика та контроль маститу: інтеграція мікробіологічних та управлінських підходів

Максим Віталійович Шевченко
Аспірант
Білоцерківський національний аграрний університет
09117, пл. Соборна, 8/1, м. Біла Церква, Україна
https://orcid.org/0000-0002-7002-1494

Андрій Віталійович Андрійчук
Кандидат ветеринарних наук, доцент
Білоцерківський національний аграрний університет
09117, пл. Соборна, 8/1, м. Біла Церква, Україна
https://orcid.org/0000-0001-9144-5272

Володимир Петрович Гончаренко
Кандидат ветеринарних наук, доцент
Білоцерківський національний аграрний університет
09117, пл. Соборна, 8/1, м. Біла Церква, Україна
https://orcid.org/0000-0002-7279-6146

Олександр Володимирович Довгаль
Кандидат ветеринарних наук, доцент
Білоцерківський національний аграрний університет
09117, пл. Соборна, 8/1, м. Біла Церква, Україна
https://orcid.org/0000-0001-8620-8117

Анотація. Мастити – це часта причина зменшення продуктивності корів та погіршення якості молока. У цій роботі розглянутий комплекс підходів, що базуються на мікробіологічних дослідженнях та ризик-аналізі, направлених на зменшення кількості хворих на мастит корів та поліпшення якості молока. Дослідження спрямоване на вивчення мікробних агентів ізольованих з молока хворих корів та засобів забезпечення здоров'я вимені і встановлення основні небезпеки, що виникають через помилки в провадженні заходів профілактики маститів. В дослідженні були застосовані мікробіологічні дослідження молока, серветок для обробки вимені та дипінгів з використанням хромогенних середовищ. Для якісної оцінки ризику було проведене опитування менеджерів-консультантів та ветеринарних лікарів. У дослідженні представлено результати мікробіологічних досліджень 115 зразків молока, 45 багаторазових серветок та 111 зразків дипінгів із застосуванням звичайних та хромогенних середовищ. Найпоширенішими мікроорганізмами в зразках молока були *Streptococcus spp.* 34,4 % (*S. agalactiae* та *S. disgalactiae*), *Staphylococcus aureus* 31,1 %, та *Escherichia coli* 28,9 %. *Staphylococcus aureus* та *Streptococcus spp.* асоціюється з інфекційним маститом, а *Escherichia coli* – з санітарним маститом. Для зниження захворюваності на мастит важливо застосовувати цілеспрямовані заходи, направлені на різні категорії збудників. Серветки для обтирання вимені були контаміновані збудниками асоційованими з розвитком маститу. Використання прального порошку, що містить бактерицидні компоненти, має вирішальне значення для мінімізації забруднення багаторазових серветок для вимені. Серед досліджених занурень дипінгів 40,6 % зразків мали повний бактерицидний ефект, а 9,9 % не мали бактерицидного ефекту. Встановлено 3 чинники високого ступеня ризику виникнення екологічного маститу та 6 чинників виникнення санітарного маститу. Результати досліджень були апробовані на двох молочних фермах. Виправлення ризик-факторів високого рівня небезпеки привело до підвищення якості молока за показниками соматичних клітин та кількості бактерій. Отримані результати можуть бути корисні для удосконалення системи профілактики та оптимізації лікування маститів на молочних фермах

Ключові слова: санітарний мастит; інфекційний мастит; ризик маститу; аналіз ризику; дипінги після доїння; збудники маститу; поліпшення якості молока; *Streptococcus spp.*; *Staphylococcus spp*.

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 26(7), 34-44

UDC 630*12: 630*181
DOI: 10.48077/scihor7.2023.34

Provenance tests of *Pinus sylvestris* L.: Estimation at the age of the half-rotation period

Yaroslav Fuchylo
Doctor of Agricultural Sciences, Professor
Malyn Applied College
11645, 1 M. Maclaii Str., Hamarnia vil., Ukraine
Institute of Bioenergy Crops and Sugar Beet NAAS
03141, 25 Klinichna Str., Kyiv, Ukraine
https://orcid.org/0000-0002-2669-5176
Yuriy Hayda
Doctor of Agricultural Sciences, Professor
Separated subdivision of National University of Life and Environmental Sciences of Ukraine
"Berezhany Agrotechnical Institute"
47500, 20 Academichna Str., Berezhany, Ukraine
Chernihiv Polytechnic National University
14027, 85 Shewchenko Str., Chernihiv, Ukraine
https://orcid.org/0000-0001-6019-9654
Ihor Ivanyuk
Doctor of Agricultural Sciences, Professor
Malyn Applied College
11645, 1 M. Maclaii Str., Hamarnia vil., Ukraine
https://orcid.org/0000-0002-4969-8783
Olga Mazhula
PhD in Agricultural Sciences
Institute of Bioenergy Crops and Sugar Beet NAAS
03141, 25 Klinichna Str., Kyiv, Ukraine
https://orcid.org/0000-0002-0241-5280
Tetiana Ivaniuk*
PhD in Agricultural Sciences, Associate Professor
Polissia National University
10002, 7 Stary Blvd., Zhytomyr, Ukraine
https://orcid.org/0000-0001-6171-4064

Article's History:
Received: 30.04.2023 Revised: 20.06.2023 Accepted: 12.07.2023

Suggested Citation:
Fuchylo, Ya., Hayda, Yu., Ivanyuk, I., Mazhula, O., & Ivaniuk, T. (2023). Provenance tests of *Pinus sylvestris* L.: Estimation at the age of the half-rotation period. *Scientific Horizons*, 26(7), 34-44. doi: 10.48077/scihor7.2023.34.

*Corresponding author

Abstract. The study of geographical crops is relevant because they are one of the reliable tools for identifying possible scenarios for the response of forest woody plant species to climate change. The purpose of the study of geographical crops of Scots pine established in 1981 in the Kyiv Oblast was to compare the growth and productivity of provenances in different age periods, determine the optimal time for early and final diagnosis of their ranking, and model the relationship between the growth and survivability indicators of provenances with climatic and other environmental variables at the age of 21, 32, and 37 years. The ANOVA method established a statistically significant influence of the geographical origin of seeds on the growth of geographical crops. At the age of 37, the capacity for survival varies from 25% (Lviv provenance) to 36.2% (Chernihiv provenance). At this age, populations from Lviv, Kyiv, and Cherkasy oblasts are characterised by the highest height. According to the intensity of radial growth, these same provenances are distinguished, as well as variants from Volyn and Luhansk. In terms of the stock of stem wood, the best is provenance from the Chernihiv Oblast. Stabilisation of the ranks of provenances in terms of survivability, growth, and productivity is observed only after 21 years. It is assumed that the most accurate assessment of the growth and condition of Scots pine provenances can be obtained at an age that corresponds to a third or a half of the age of the main felling. The trend of clinal variability in the survival of provenances and the average diameter of their trunks along the geographical (latitudinal) and ecological (temperature) gradients is revealed. The study results can be used to update the current forest-seed zoning of Ukraine

Keywords: geographical variability; growth indicators; capacity for survival; rank correlation; clinal variability

INTRODUCTION

One of the most urgent tasks of forest science is to determine the scenarios and consequences of forest adaptation to climate change. To predict such scenarios and develop mitigation measures, reliable information on the possible response of individual elements of forest ecosystems to climate change is needed. It is likely that in order to ensure effective forest reproduction in the new climatic conditions, it would be advisable to transfer more adapted forest reproductive material from other regions.

When assessing and running the dynamics of growth and stability of forest woody plants under climate change, data from the study of geographical crops are widely used, that is, experimental crops in which the offspring of geographically distant populations of a certain species that were formed under different climatic conditions are tested on a homogeneous ecological background. Therefore, measurements and surveys of such geographical crops, their analysis, carried out for a long time, allow forming a database for monitoring and predicting changes in the productivity of forest stands, to update forest-seed zoning in the context of climate change.

Studies of intraspecific variability of Scots pine in geographical cultures have more than two hundred years of history and continue in many countries of the world. Swedish researcher Andersson Gull *et al.* (2018), studying the phenology of seven-year-old Scots pine seedlings of various geographical origins, found that if the climate warms, its northern provenances may suffer from spring frosts due to the earlier beginning of the growing season. At the same time, it was found that the high genetic variability of Scots pine can provide sufficient potential for its adaptation to new climatic conditions by breeding.

Kivimäenpää *et al.* (2018) investigated the emission of biogenic volatile organic compounds from shoots and litter of four provenances of Scots pine in the northern part of its range (latitude from 58° up to 68°N). It was found that Finnish northern and southern origins differed significantly in the level and profile of volatile organic compound emissions. Matisons *et al.* (2021) in order to study the principles of climate-reasonable forest management, investigated five parallel geographical crops of Scots pine within the south-eastern Baltic region (in Latvia and Germany). Based on the assessment of the relationship between weather characteristics and growth and their heritability, it was found that the sensitivity of provenance growth can be an additional feature in the selection of forest reproductive material that is most suitable for new climatic conditions.

Barzdajn *et al.* (2016) focused on studying the variability and growth of 19 Scots pine populations in 30-year-old geographical crops in northeastern Poland. Significant interpopulation variability was found in all indicators and growth, but the greatest – in the stock of stem wood. The best in this experiment were provenances originating from the latitudinal zone between 49°N and 54°N. It is interesting that it is within this belt that the populations of Scots pine represented in the geographical cultures that were the object of our research are located.

Forests can play an important role in carbon deposition and thus contribute to reducing greenhouse gases in the atmosphere. Chmura *et al.* (2021) assessed the level of carbon sequestration by provenances of Scots pine and European spruce. It is established that there are a number of provenances that are characterised by a significantly greater ability to accumulate carbon, and therefore, it is concluded that it is possible to increase the level of carbon sequestration by breeding methods.

In a study of 57-year-old geographical crops of Scots pine in Poland by Szaban *et al.* (2023), emphasis is

placed on the variability of wood density between provenances. Researchers statistically confirmed the influence of the genotype on the physical and mechanical properties of wood, in particular its density. Researchers Notivol *et al.* (2020) from Spain used data on the growth and capacity for survival of Scots pine provenances in multi-site geographical crops aged 5, 10, and 15 years to test various strategies for selecting seed sources for reforestation (seed sourcing strategies) in the context of climate change. It was found that strategies based on the selection of a single population (provenance) are preferable to strategies for using mixed seed sources.

Ballian & Šito (2017) investigated the growth and phenology of 14 European Scots pine provenances in an international experiment in Zepce in central Bosnia and Herzegovina. In these cultures, one provenance from Ukraine (from the Ivano-Frankivsk Oblast) is also tested. Differentiation of variants by capacity for survival, height, and diameter of the root neck was revealed. Memišević Hodžić *et al.* (2020) conducted their research on junior geographical Scots pine crops established in 2012 also in Bosnia and Herzegovina. It is noted that the adaptability of pine provenances is determined not only by their genetic structure, but also by the conditions of the environment in which they are cultivated. Gülcü & Bilir (2017) studied geographical culutras of Scots pine laid well south of its natural range in Turkey. It was found that almost all provenances in both test sites grow better than native species (Black pine and Taurus cedar).

Evidently, along with the traditional tasks of genecology (determining the level and scope of intraspecific variability of Scots pine by morphological, biochemical, physical, and mechanical characteristics) in trees of different ages, identifying the best populations as seed sources), the current trend of most modern studies of geographical cultures is aimed at building and using models that illustrate the conditionality of the growth and development of pine provenances by various environmental factors and developing strategies for adapting forest ecosystems to various climate change scenarios.

The purpose of the study was a comparative assessment of the growth and productivity of Scots pine provenances in geographical cultures of Scots pine near Kyiv in different age periods, determination of the optimal time for early and final diagnostics of their ranking, and modelling the relationship of growth indicators and capacity for survival of provenances with climatic and other environmental variables.

MATERIALS AND METHODS

The research was conducted on the basis of data from systematic and long-term measurements and accounting in geographical crops of Scots pine, which were created in 1981 in the Dzvonkovsky Forestry (sq. 62) at the Boyarka forest experimental station. In experimental crops, the offspring of populations from the southern part of the Scots pine range are tested on an area of 2.6 hectares (Table 1). The soil of the experimental site is sod-weakly podzolic, clay-sandy on fluvioglacial deposits, and the type of forest-growing conditions is fresh subor (B_2). Seeds for creating crops were collected in the mother plantings also in fresh subor conditions.

Table 1. *Description of the places of origin of seeds for creating geographical crops of Scots pine*

No.	Origin			Latitude (N)	Longitude (E)	Height AMSL, m	Soils
	Oblast	Enterprise	Forestry				
1	Volyn	Kovel forestry	Starovyzhivske, sq. 14	51°27′	24°31′	161	sod-medium-podzolic, gleyed sandy loam
2	Zhytomyr	Poliskyi forestry	Radynske, sq. 40	51°14′	28°52′	126	sod-medium podzolic gleyed sandy loam
3	Chernihiv	Novgorod-Siverskyi forestry	Volodymyretske, sq.10	52°07′	32°44′	145	sod-medium-podzolic sandy loam
4	Lviv	Radekhivskyi forestry	Radekhivske, sq. 41	50°13′	24°42′	221	sod-weakly podzolic sandy
5	Cherkasy	Cherkaskyi forestry	Ruskopolyanske, sq. 44	49°30′	31°59′	80	sod-weakly podzolic sandy
6	Kyiv	Boyarka FES	Dzvinkivske, sq. 47	50°16′	30°8′	190	sod-medium-podzolic sandy loam
7	Sumy	Lebedynskyi forestry	Radianske, sq. 48	50°38′	34°40′	114	grey podzolised
8	Luhansk	Kremenskyi forestry	Komsomolske, sq. 36, 42	48°32′	39°28′	110	sod-weakly podzolic

Source: *compiled by the authors*

Pine provenances were tested in geographical cultures in two repetitions. 444 seedlings of one provenance were planted in 12 rows on each plot. Layout of planting spots – 2×1 m. This design of the experiment allows carrying out tests over a long period of time. Populations of Scots pine, whose offspring are tested in geographical cultures, represent the southern part of the range of Scots pine. In this part of the range, fluctuations in the average annual air temperature between the places of seed origin are 2.1°C, and the amplitude of the growing season duration is 14 days (Table 2).

Table 2. *Climatic conditions of seed origin sites*

No.	Origin (Oblast)	Average annual air temperature, °C	Average annual air temperature in January, °C	Average annual air temperature in July, °C	Precipitation (May-October), mm	Sum of temperatures (May-October), °C	Duration of sunshine (May-October), hours	Duration of the growing season, days
1	Volyn	8.2	-1.9	19.1	408	2,875	1,293	206
2	Zhytomyr	8.1	-2.7	19.8	348	2,800	1,337	199
3	Chernihiv	7.1	-4.2	19.4	366	2,885	1,388	196
4	Lviv	8.3	-2.2	19.1	492	2,695	1,287	205
5	Cherkasy	8.8	-2.8	21.3	330	3,040	1,413	204
6	Kyiv	8.1	-2.9	20.0	336	3,020	1,381	204
7	Sumy	7.6	-4.1	20.2	351	2,890	1,391	194
8	Luhansk	8.9	-4.3	22.7	288	3,365	1,464	208

Source: *compiled by the authors*

The growth, productivity, and stability of Scots pine provenances were evaluated by the following indicators: tree height (H), trunk diameter at breast height (DBH), volume of wood stock per 1 ha (VOL), and % capacity for survival (Surv). The obtained data was processed by statistical modules using the STATISTICA software suite, in particular Basic Statistics and Multiple Regression. Variation analysis was performed using the Anova statistical module and the model:

$$Y_{ijk} = \mu + P_i + R_k + P_i \times R_k + e_{ijk},$$

where Y_{ijk} – *ijk*-th observation; μ – total mean; P_i – fixed effect of *i*-th origin; R_k – random effect of *k*-th replication; $P_i \times R_k$ – random effect of interaction between *i*-th origin and *k*-th replication; e_{ijk} – residual error of *ijk*-th observation.

To analyse the dynamics of growth and productivity of production, the authors used data from measurements and accounting that were carried out at the ages of 21, 32, and 37 years.

RESULTS AND DISCUSSION

One of the most important tasks in the study of geographical cultures of forest woody plant species is to assess the dynamics of ranking provenances by various parameters. As can be seen from the correlation matrix (Table 3), during the first 5-year period, the ranks of Scots pine provenances in terms of average height changed slightly, since Spearman's rank correlation coefficient was quite high $r_{1\text{-}5}$=0.575 and statistically significant for p<0.10. However, over the next 6 years, there were more noticeable changes in the ranks of provenances compared to annual crops ($r_{1\text{-}11}$=0.037), while significantly less relative to 5-year ones ($r_{5\text{-}11}$=0.540). An assessment of the dynamics of provenances by average height in older geographical cultures (at the age of 21, 32, 37 years) showed that the order of ranks that developed in 21-year-old cultures had little change over time. Spearman's correlation coefficients are $r_{21\text{-}32}$=0.673, $r_{32\text{-}37}$=0.661, $r_{21\text{-}37}$=0.794, respectively, and are statistically significant for p<0.05.

Table 3. *Matrix of Spearman's rank correlation coefficients of mean height (H) and mean trunk diameter (DBH) of pine provenances*

Variable	H1	H5	H11	H21	H32	DBH11	DBH21	DBH32
H5	0.575							
H11	0.037	0.540						
H21	0.018	0.447	0.489					
H32	0.079	0.330	0.061	0.673*				
H37	0.030	0.361	0.251	0.794**	0.661*			
DBH21						-0.012		
DBH32						-0.062	0.879***	
DBH37						-0.272	0.770**	0.721*

Note: *correlation coefficients are significant for: * – p<0.05, ** – p<0.01, *** – p<0.001*
Source: *compiled by the authors*

The change in the ranks of provenances of Scots pine in terms of trunk diameter occurred with a similar pattern. It is worth noting that at the age of one and five, this indicator was not determined in experimental crops due to the fact that not all trees reached the height (1.3 m) at which this indicator is measured. Therefore, the first order of rank for the average trunk diameter was obtained at the age of 11 years. All subsequent ranking schemes in older cultures differed significantly from it, as evidenced by the corresponding rank correlation coefficients: r_{11-21}= -0.012, r_{11-32} = -0.062, r_{11-37}= -0.272. Rank stabilisation by the average trunk diameter occurred only after 20 years: r_{21-32}=0.879, significant for p<0.001 and r_{21-37}=0.770, significant for p<0.01.

Schemes for ranking Scots pine provenances by the percentage of survival of the number of planted plants and the stock of stem wood, which was formed before the age of 11 years, later changed significantly, as evidenced by low values of correlation coefficients (Table 4). A certain stabilisation of the ranks of provenances in these parameters began to be observed in 21-year-old geographical cultures. A significant change in stock ranks, which was observed in the period 32-37 years, is explained by the consequences of the 2012 snowbreak.

Table 4. *Matrix of Spearman's rank correlation coefficients of the capacity for survival (Surv) and volume of wood stock (VOL) of pine provenances*

Variable	Surv5	Surv11	Surv21	Surv32	Vol11	Vol21	Vol32
Surv11	0.647*						
Surv21	0.377	0.463					
Surv32	0.325	0.409	0.671*				
Surv37	-0.221	-0.091	0.311	0.707*			
Vol21					0.474		
Vol32					0.221	1	
Vol37					-0.080	0.176	-0.012

Note: *correlation coefficients are significant for: * – p<0.05, ** – p<0.01, *** – p<0.001*
Source: *compiled by the authors*

The analysis of indicators of the capacity for survival, growth, and productivity of Scots pine provenances was carried out during the time period of stabilisation of their growth, namely, after geographical crops reached the age of 21 (Table 5). This period of development of pine stands is characterised by increased intraspecific competition for light, water and mineral nutrition elements, and intensive thinning of plantings.

Table 5. *Capacity for survival, growth, and productivity of geographical crops of Scots pine*

No.	Origin (Oblast)	21 years				32 years				37 years			
		Surv, %	H, m	DBH, cm	Vol, m^3	Surv, %	H, m	DBH, cm	Vol, m^3	Surv, %	H, m	DBH, cm	Vol, m^3
1	Volyn	54.0±3.1	9.8±0.27	10.1±0.15	170	48.7±3.1	15.4±0.32	13.7±0.21	297	28.6±2.8	17.6±0.34	16.9±0.26	288
2	Zhytomyr	68.8±2.9	10.2±0.20	10.2±0.14	180	50.8±3.1	15.4±0.33	14.1±0.23	324	34.5±2.9	18.0±0.26	16.7±0.29	308
3	Chernihiv	64.8±2.9	10.9±0.49	10.4±0.16	202	52.1±3.1	16.4±0.31	14.4±0.23	373	36.2±3.0	18.3±0.37	16.9±0.29	422
4	Lviv	70.1±2.8	11.0±0.16	10.2±0.13	197	48.7±3.1	15.8±0.34	14.3±0.23	330	25.0±2.7	19.2±0.38	17.7±0.33	275
5	Cherkasy	64.8±2.9	10.4±0.25	10.8±0.13	176	46.6±3.1	16.3±0.27	14.3±0.22	327	28.0±2.8	18.9±0.34	17.2±0.31	277
6	Kyiv	79.4±2.5	10.3±0.23	9.7±0.14	222	55.7±3.1	15.2±0.33	13.8±0.22	357	32.2±2.9	19.0±0.40	16.9±0.32	348
7	Sumy	65.3±2.9	10.2±0.22	9.9±0.13	172	46.0±3.1	14.3±0.41	13.6±0.22	259	30.7±2.8	17.6±0.44	16.6±0.27	393
8	Luhansk	57.2±3.0	10.0±0.20	9.9±0.16	140	43.9±3.1	14.9±0.22	13.8±0.27	263	30.7±2.8	18.1±0.36	17.0±0.31	317

Source: *compiled by the authors*

Evidently from Table 5, the capacity for survival of provenances decreased the least during this period in the Volyn population (25.4%), and the most in the Kyiv population (47.2%). These figures reflect not only the intensity of natural thinning, but also partly the consequences of snowbreak.

In 37-year-old crops, the capacity for survival of Scots pine provenances from Ukraine ranged from 25% (Lviv provenance) to 36.2% (Chernihiv). At this age, the highest height is characterised by variants from Lviv, Kyiv, Cherkasy, Chernihiv oblasts. The highest intensity of radial growth is distinguished by the same provenances, as well as variants from Volyn and Luhansk. In terms of stem wood reserves, the best is provenance from Chernihiv Oblast, and among the worst – from Volyn and Lviv oblasts.

The growth of non-regional provenances with the local one, there is no population that is significantly better than the local one in terms of average height at the age of 37, but 3 populations (Volyn, Zhytomyr, Sumy) are significantly worse (t=2.10-4.4, $t_{0.05}$=2.06). According to the average trunk diameter, there are also no provenances that grow better than the local one. A two-factor analysis of the growth indicators of Scots pine provenances revealed a statistically significant influence of geographical origin on their growth in height and diameter at the age of 21, 32, and 37 years (Table 6).

Table 6. *Results of dispersion analysis of the growth of Scots pine provenances by height and diameter*

Indicators	Age	Effect	LS	SS	DF	MS	F	p
Height	21	Free term	***	25,875.70	1	25,875.70	15,832.42	0.0001
		Provenance	*	35.44	9	3.94	2.41	0.0126
		Repetition	ns	1.50	1	1.50	0.91	0.3398
		Prov. × Repeat.	ns	13.72	9	1.52	0.93	0.4973
		Error		367.73	225	1.63		
	32	Free term	***	57,103.57	1	57,103.57	25,718.58	0.0001
		Provenance	***	143.36	9	15.93	7.17	0.0001
		Repetition	**	22.59	1	22.59	10.17	0.0016
		Prov. × Repeat.	ns	38.36	9	4.26	1.92	0.0501
		Error		517.34	233	2.22		
	37	Free term	***	101,147.3	1	101,147.3	28,557.27	0.0001
		Provenance	***	158.4	9	17.6	4.97	0.0001
		Repetition	ns	12.5	1	12.5	3.53	0.0613
		Prov. × Repeat.	***	130.2	9	14.5	4.08	0.0001
		Error		1,041.3	294	3.5		
Diameter at a height of 1.3 m	21	Free term	***	346,273.8	1	346,273.8	52,953.91	0.0001
		Provenance	***	635.5	9	70.6	10.80	0.0001
		Repetition	***	225.7	1	225.7	34.52	0.0001
		Prov. × Repeat.	***	332.7	9	37.0	5.65	0.0001
		Error		23,017.8	3,520	6.5		
	32	Free term	***	504,311.3	1	504,311.3	39,127.91	0.0001
		Provenance	***	1,065.1	9	118.3	9.18	0.0001
		Repetition	ns	5.9	1	5.9	0.46	0.4997
		Prov. × Repeat.	***	445.9	9	49.5	3.84	0.0001
		Error		34,632.2	2,687	12.9		
	37	Free term	***	459,022.5	1	459,022.5	34,505.09	0.0001
		Provenance	***	1,023.1	9	113.7	8.55	0.0001
		Repetition	***	399.6	1	399.6	30.04	0.0001
		Prov. × Repeat.	***	450.5	9	50.1	3.76	0.0001
		Error		22,375.7	1,682	13.3		

Note: *SS – sum of squares; LS – level of significance: ***p<0.001, **p<0.01, *p<0.05; ns –not significant; DF – degrees of freedom; MS – mean square; F – value of F-statistics; p – significance level*
Source: *compiled by the authors*

Correlation and regression analyses were performed to assess the impact of indicators that characterise the place of seed harvesting on the growth and stability of Scots pine provenances. As can be seen from the Table 7, at the age of 21, the calculated paired correlation coefficients were statistically insignificant. Later, at the age of 32 and 37 years, there is a direct positive relationship between the geographical latitude of the

seed origin and the capacity for survival of provenances in geographical crops (Pearson correlation coefficients r=0.695 and 0.675 are significant for p<0.05). The relationship between the growth indicators of provenance (height and diameter of the trunk) and the geographical coordinates of the seed source is described by negative values of correlation coefficients (both significant and insignificant), that is, the best growth of the offspring of southern and western provenances is distinguished. At the same time, these growth rates at an older age (32 and 37 years) directly correlate with the average annual temperature and duration of the growing season, and the capacity for survival of provenances is inversely correlated.

Table 7. *Pearson correlation coefficients between capacity for survival (Surv), height (H), trunk diameter (DBH), and geographical coordinates (N, E), average annual air temperature (AAT), and growing season duration (GS)*

Age Indicators	21			32			37		
	Capacity for survival (Surv.)	Height (H)	Diameter (DBH)	Capacity for survival (Surv.)	Height (H)	Diameter (DBH)	Capacity for survival (Surv.)	Height (H)	Diameter (DBH)
N	0.299	-0.049	-0.329	0.695**	-0.157	-0.438	0.675**	-0.591*	-0.611*
E	-0.115	-0.254	-0.240	-0.123	-0.328	-0.276	0.347	-0.209	-0.369
AAT	-0.333	-0.016	0.443	-0.572*	0.302	0.483	-0.696**	0.505	0.669**
GS	-0.375	-0.001	0.343	-0.475	0.377	0.465	-0.699**	0.564*	0.675**

Note: *Significance level: ***p<0.01, **p<0.05, *p<0.1*
Source: *compiled by the authors*

The statistical significance of paired correlation coefficients between the indicators of the capacity for survival and growth of provenances and the geographical latitude of the location of mother plantings, the average annual air temperature and the duration of the growing season at the seed harvesting point prompted regression analysis, which resulted in a number of adequate one-factor linear models (Table 8).

Table 8. *Mathematical models for estimating the capacity for survival and diameter at breast height of Scots pine provenances*

Model number	Analytical form of the model (model adequacy criteria)
1	Surv32 = -138.4 + 3.7N (R^2=0.483, F=7.48, p<0.026)
2	Surv37 = -99.9 + 2.6N (R^2=0.456, F=6.71, p<0.032)
3	Surv37 = 68.8 - 4.6AAT (R^2=0.484, F=7.52, p<0.025)
4	DBH37 = 10.8 + 0.7AAT (R^2=0.448, F=6.49, p<0.034)
5	Surv37 = 154.5 – 0.6GS (R^2=0.488, F=7.63, p<0.025)
6	DBH37 = -2.9 + 0.1GS (R^2=0.455, F=6.69, p<0.032)

Note: $F_{table\ 0.05}(1.8) = 5.32$
Source: *compiled by the authors*

The obtained mathematical models, in particular signs and values of regression coefficients in them, indicate that in 32-year-old geographical crops of Scots pine, an increase in the latitude of the place of harvesting Scots pine seeds by one degree caused an increase in the capacity for survival of provenance by 3.7%, and in 37-year-olds – by 2.6%. The capacity for survival of offspring of populations at 37 years of age decreased by 4.6%, if the average annual air temperature of the location of the mother plant increased by 1^{about}C, and by 0.6% – when the duration of the growing season in the region of seed harvesting increased by 1 day. The obtained adequate regression models, in which the regressant is the average diameter of the trunk of provenances, and the regressor is the geographical latitude of the seed source, allow asserting with some caution about the manifestation of clinal variability of the trunk diameter at breast height in the studied part of its range in Scots pine. In addition, Table 8 shows that an increase in the average annual air temperature in the seed source by 1°C caused an increase in the average trunk diameter of 37-year-old provinces by 0.7 cm, and the extension of the growing season by 1 day caused an increase in this indicator by only 0.1 cm.

The scientific debate about the age at which final conclusions can be drawn about the stabilisation of provenances ranks has been going on for a long time. König (2005) suggests that it is advisable to observe

geographical cultures from at least one-third to one-half of the age of logging turnover. Our research supports the view that early diagnosis (up to 10 years) of population growth does not always guarantee reliable final conclusions. Similar to the results of a study of geographical beech crops conducted by Kleinschmit and Svolba (1995), the data obtained (Table 3) indicate the presence of a significant (although statistically insignificant) correlation between the ranks of provenances by height in the age range of 5 and 11 years and a weak one in the intervals of 5-21, 5-32, 5-37 years. The order of ranks of provenances, which was in 11-year geographical cultures, was not preserved later, as evidenced by low (even negative) rank correlation coefficients for pairs of 11-21, t11-32, and 11-37 years. Therefore, to answer the question of the optimal age for early and final diagnosis of provenance growth, it is necessary to continue studying geographical cultures, which are also created according to the "long-term" design.

The populations that are represented in the studied geographical cultures represent the southern part of the Scots pine range, both continuous and disjunctive (marginal). This territory extends from North to South for 500 km, from West to East – for 1,100 km. Many provenances from this part of the pine range have been tested for a long time in a number of other geographical crops. Tereshchenko *et al.* (2008), who conducted the most recent studies of these crops, found that at the age of 90, the highest productivity was characterised by local (Sumy) pine. According to the study, Sumy provenance in terms of volume of stem wood reserve (393 $m^{3*}ha^{-1}$) is one of the best in the conditions of the Kyiv Polissia.

Since 1972, for 20 years in the Kharkiv and Donetsk oblasts near the southern border of the Left-Bank Forest-Steppe, a number of geographical crops have been established, where 169 provenances of Scots pine from almost all parts of its range on the territory of the former Soviet Union are tested. As a result of many years of research by Zhurova (2007), 11 provenances were recommended for use as seed sources, among which three (Cherkasy, Sumy, Kyiv) are similar in origin to those tested in crops near Kyiv.

In 1974-1976, under the methodological guidance of A.M. Shutyaev, a large-scale project was implemented to test 113 provenances of Scots pine in 33 locations in the former Soviet Union. According to the results of studies by Shutyaev and Giertych (2000) of the growth dynamics of 5-20-year-old offspring of populations, the range of pine is divided into 9 parts, one of which (Western Continetntal) covers the region of provenances, which are also tested in crops in 1981 near Kyiv. And again, Ukrainian ancestry is characterised by outstanding growth in height in most European locations.

The range of intraspecific variability of Scots pine, which is found in geographical cultures, depends on the breadth of their coverage of the species' range. Barzdajn *et al.* (2016), investigating one of the five geographical Scots pine crops of the IUFRO experimental programme, which presents 20 provenances from all over Europe (amplitude 40°-60°N, 4°-33°E), found significant differentiation of populations in all indicators of growth and capacity for survival. In particular, in terms of wood reserves, the variation reached 92%. Given the relatively small proportion of the pine range represented by provenances in geographical cultures, a significant change in growth rates should not be expected. Evidently from Table 5, at the age of 32 and 37 years, the range of fluctuations in average heights was 2.2-2.4 m (CV=4.9% and 4.0%), and average trunk diameters – 2.0-2.6 cm (CV=4.6% and 4.5%). At the same time, the variation in productivity due to a significant variation in capacity for survival was more noticeable (CV=15.7% and 11.6%).

One of the important theoretical and applied tasks of genecological research is to identify the nature of variability in adaptive and quantitative characteristics of a forest tree species. Starting from the paper by Langleta (1959), which has already become a classic and which proved the existence of an almost functional relationship between the length of the day and the dry matter content in the needles of Scots pine seedlings of various geographical origin, later studies of geographical cultures of many species of woody plants revealed clinal variation along the geographical (ecological) gradients of other features: Cunningham and Haverbeke (1991) – winter colour of needles, Oleksyn *et al.* (1998) – duration of the shoot growth period, Zhelev and Lust (1999) – intensity of growth by diameter, Andersen and Fedorkov (2004) – frost resistance.

In some parts of the range of Scots pine, clinal variation of adaptive features is observed. Hall *et al.* (2021) found such a model of variability for frost resistance in the latitudinal and longitude directions. The constructed significant regression models allow making assumptions about the possible clinal nature of the variation in the percentage of survivability of provenances and the average trunk diameter at breast height. At the same time, the variability of the average height of provenances is not characterised by clinality in experimental cultures. The reason for this is that some of the populations presented here are marginal at the southern border of the Scots pine range, the gene flow between which is limited due to spatial remoteness.

CONCLUSIONS

Long-term (for more than 25 years) studies of Scots pine provenances in geographical cultures near Kyiv have shown that early (at the age of 11 years) diagnosis of the capacity for survival, growth, and productivity of Scots pine provenances is uninformative. Stabilisation of the ranks of provenances in these indicators is observed only after 21 years. A more reliable assessment of the growth and condition of the offspring of Scots pine populations in geographical cultures can be

obtained at an age that corresponds to a third to half of the age of the main felling.

Despite the relatively low variation in the indicators of the average height, average trunk diameter, and volume of stem wood stock of Scots pine provenances, the effect of influencing them by the geographical origin of seeds is statistically significant.

The trend of clinal variability in the survival of provenances and the average diameter of their trunks along the geographical (latitudinal) and ecological (temperature) gradients is revealed. The marginality of Scots pine populations at the southern border of its range, which is accompanied by a low intensity of gene flows, obviously limits the manifestation of a clear model of clinal variation of traits in their offspring in geographical cultures.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

None.

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Географічні культури *Pinus sylvestris* L.: оцінка у віці половини ротаційного періоду

Ярослав Дмитрович Фучило
Доктор сільськогосподарських наук, професор
Малинський фаховий коледж
11645, вул. М. Маклая, 1, с. Гамарня, Україна
Інститут біоенергетичних культур і цукрових буряків НААН
03141, вул. Клінічна, 25, м. Київ, Україна
https://orcid.org/0000-0002-2669-5176

Юрій Іванович Гайда
Доктор сільськогосподарських наук, професор
Відокремлений підрозділ Національного університету біоресурсів і природокористування України «Бережанський агротехнічний інститут»
47500, вул. Академічна, 20, м. Бережани, Україна
Національний університет «Чернігівська політехніка»
14027, вул. Шевченка, 85, м. Чернігів, Україна
https://orcid.org/0000-0001-6019-9654

Ігор Дмитрович Іванюк
Доктор сільськогосподарських наук, професор
Малинський фаховий коледж
11645, вул. М. Маклая, 1, с. Гамарня, Україна
https://orcid.org/0000-0002-4969-8783

Ольга Степанівна Мажула
Кандидат сільськогосподарських наук
Інститут біоенергетичних культур і цукрових буряків НААН
03141, вул. Клінічна, 25, м. Київ, Україна
https://orcid.org/0000-0002-0241-5280

Тетяна Миколаївна Іванюк
Кандидат сільськогосподарських наук, доцент
Поліський національний університет
10008, б-р Старий, 7, м. Житомир, Україна
https://orcid.org/0000-0001-6171-4064

Анотація. Дослідження географічних культур є актуальним з огляду на те, що вони є одним із надійних інструментів виявлення можливих сценаріїв реакції видів лісових деревних рослин на зміну клімату. Метою досліджень створених у 1981 році географічних культур сосни звичайної у Київській області була порівняльна оцінка росту і продуктивності провенієнцій у різні вікові періоди, визначення оптимального часу ранньої та кінцевої діагностики їх ранжування та моделювання взаємозв'язку показників росту і збереженості провенієнцій з кліматичними та іншими середовищними змінними у віці 21, 32 та 37 років. Методом ANOVA встановлено статистично значущий вплив географічного походження насіння на ріст географічних культур. У 37-річному віці збереженість варіює від 25 % (Львівська провенієнція) до 36,2 % (Чернігівська провенієнція). У цьому віці найбільшою висотою характеризуються популяції із Львівської, Київської, Черкаської областей. За інтенсивністю радіального приросту виділяються ці ж самі провенієнції, а також варіанти з Волині і Луганська. За запасом стовбурової деревини найкращою є провенієнція з Чернігівської області. Стабілізація рангів провенієнцій за показниками збереженості, росту і продуктивності спостерігається лише після 21 року. Зроблено припущення, що найбільш точну оцінку росту і стану провенієнцій сосни звичайної можна отримати у віці, який відповідає третині-половині віку головної рубки. Виявлено тренд клінальної мінливості збереженості провенієнцій і середнього діаметра їх стовбурів вздовж географічного (широтного) та екологічного (температурного) градієнтів. Результати досліджень можуть бути використані при актуалізації діючого лісонасіннєвого районування України

Ключові слова: географічна мінливість; показники росту; збереженість; рангова кореляція; клінальна мінливість

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 26(7), 45-53

UDC: 631.531:633.81:633.82
DOI: 10.48077/scihor7.2023.45

Economic and biological value of medicinal and fodder herbs for feed production

Mykola Shtakal*
Doctor of Agricultural Sciences, Senior Research Fellow
National Scientific Center "Institute of Agriculture NAAS"
08162, 2-b Mashynobudivnykiv Str., Chabany, Ukraine
https://orcid.org/0000-0002-9511-0290
Mykola Tkachenko
Doctor of Agricultural Sciences, corresponding member of NAAS
National Scientific Center "Institute of Agriculture NAAS"
08162, 2-b Mashynobudivnykiv Str., Chabany, Ukraine
https://orcid.org/0000-0001-6128-4703
Larysa Kolomiiets
PhD in Agricultural Sciences, Senior Research Fellow
National Scientific Center "Institute of Agriculture NAAS"
08162, 2-b Mashynobudivnykiv Str., Chabany, Ukraine
https://orcid.org/0000-0003-3408-8541
Liubov Holyk
PhD in Agricultural Sciences, Senior Research Fellow
National Scientific Center "Institute of Agriculture NAAS"
08162, 2-b Mashynobudivnykiv Str., Chabany, Ukraine
https://orcid.org/0000-0002-7157-6520
Oleksii Ustymenko
PhD in Agricultural Sciences, Senior Research Fellow
The Research Station of the Medicinal Plants of the Institute of Agroecology and Environmental Management of the NAAS
37535, 16-A Pokrovska Str., Berezotocha vill., Ukraine
https://orcid.org/0000-0002-5321-6812

Article's History:
Received: 1.05.2023
Revised: 25.06.2023
Accepted: 13.07.2023

Abstract. The relevance of the research lies in the need to involve in the feed production of grass species containing biologically active substances for use as natural animal growth stimulants. The purpose of the study was to experimentally establish the economic and biological value of medicinal and fodder grass species, their technological suitability for growing in clean crops, obtaining raw materials and forming phyto-mixtures from them for use as organic feed additives**.** In the course of conducting research, the following methods were used: field, laboratory, analytical,

Suggested Citation:
Shtakal, M., Tkachenko, M., Kolomiiets, L., Holyk, L., & Ustymenko, O. (2023). Economic and biological value of medicinal and fodder herbs for feed production. *Scientific Horizons*, 26(7), 45-53. doi: 10.48077/scihor7.2023.45.

*Corresponding author

and statistical. The economic and biological value for the growth of the following types of medicinal herbs in the feed production was determined: hyssop, fennel, white horehound, Moldavian dragonhead, coriander, yarrow, purple coneflower, dandelion, milk thistle, anise hyssop, St. John's wort, sneezeweed, sweet wormwood. It was established that annuals in the year of sowing, and perennial species in the second or fourth years of use provided a dry mass of grasses – 1.7-5.0 t/ha and seeds – 0.3-1.8 t/ha. These types of herbs contain biologically active substances (polysaccharides, essential oils, flavonoids, organic acids, mainly vitamins, and trace elements) that have a positive effect on the animal body. The technological suitability for harvesting raw materials and forming phyto-mixtures of the following species is also proved: milk thistle, Moldavian dragonhead, coriander, hyssop, fennel, purple coneflower, anise hyssop, white horehound, and yarrow. As a result of the research, a database was created on the selection of medicinal herbs, their technological suitability for cultivation, and optimal harvesting times for harvesting raw materials with subsequent use in feed production. The inclusion of medicinal and feed species in feeding rations can ensure the production of organic livestock products that meet the requirements of the European Green Deal strategy

Keywords. medicinal and fodder species; yield; chemical composition; technological suitability; phyto-mixtures; biologically active substances; raw materials; harvesting time

INTRODUCTION

Numerous studies, in particular, by researchers of the National Academy of Agrarian Sciences (NAAS) have established that cereals and legumes are the most suitable for use in fodder production for feeding animals. Among the cereal species in the zone of Polissia, Forest-Steppe, and Carpathians, timothy, bromegrass, cat grass, perennial ryegrass, and meadow fescue are most often used, and among legume species – white and red clover, alfalfa, deervetches, etc. They are highly productive, have a high nutritional value and fully provide animals with all the necessary elements of nutrition (Kurhak *et al.,* 2019; 2022; Kaminskyi *et al.,* 2021). However, to further increase the productivity of farm animals in animal feeding, artificial animal growth stimulators (premixes) have been widely used in recent decades and added to animal feeding diets.

The substances of these additives in feeding livestock, even in small amounts, provide a positive physiological effect (Vdovichenko, 2017; Novakovska *et al.,* 2022). However, it turned out that the substances of these feed additives cause negative effects on the animal and human body. Therefore, the composition of these supplements has been slightly changed and, in particular, the use of antibiotics is significantly limited, as described in the papers (Darmohrai, 2018; Kryzhak, 2020). However, modern feed additives, as noted by leading scientists of Ukraine (Ibatullin, 2017; Gladiy *et al.,* 2019), worsen the quality of livestock products. Given these circumstances, as an alternative to artificial animal growth stimulants, attempts were made to use medicinal and fodder herbs as natural animal growth stimulants. It was based on the fact that medicinal herbs containing biologically active substances are widely used in medicine.

The same applies to veterinary medicine and feed production for use as biological growth stimulators of animals. This area of research is new and poorly understood. However, there are publications of previous years on the effectiveness of using purple coneflower on pigs at the Institute of Pig Breeding of NAAS and fish at the Institute of Fisheries of NAAS. Chudak (2020) and Poberezhets (2019) established the effectiveness of using pale purple coneflower on poultry (quails) at the Vinnytsia National University.

There is very limited information on the use of medicinal herbs as phytobiotics in the world. Thertefore an important task is to search for types of herbs containing biologically active substances (BAS) in feed production, as substitutes for artificial growth stimulants for feeding animals. Such attempts to include medicinal herbs in feed were the subject of study by the researchers (Chudak, 2018; De Falco, 2019). However, the very possibility of such a replacement and the list of such types of herbs, the content of biologically active substances in them (essential oils, flavonoids, organic acids, polysaccharides, etc.) and their dosage of use for certain types of farm animals are extremely insufficiently studied.

One of the ways of such application may be the inclusion of medicinal and fodder herbs such as yarrow, dandelion, chicory, oregano, etc. in the composition of sown herbage (Kurhak *et al.,* 2019; Shtakal *et al.,* 2020). However, such use is still problematic due to the inability to accurately determine the doses of medicinal and fodder herbs in cereal and legume stands, since their content varies by year, mowing, and depending on weather conditions. Therefore, this line of research still requires a thorough investigation. Some papers (Vdovichenko *et al.,* 2017; Moisiienko, 2019) indicate that a more promising way is to grow them in clean crops, followed by the preparation of phytocompositions based on them and use them as feed fortifiers or organic feed additives for feeding to farm animals. Therefore, the solution to the question of the possibility of using medicinal and fodder herbs with the content of biologically active substances as organic feed additives for feeding farm animals, in this regard, can be a new

area of research in feed production and requires a deep systematic study.

Therefore, the purpose of the study was to establish the possibility of using certain types of medicinal and fodder herbs, considering their technological suitability for growing in clean crops to obtain raw materials and create phyto-mixtures from them and use them in animal feeding.

MATERIALS AND METHODS

Field work was carried out in a stationary experiment on typical chernozems of the Panfyliv Experimental Station of the National Research Centre "Institute of Agriculture of the National Academy of Agrarian Sciences" in 2020-2022. Typical light loamy chernozems have the following physical and agrochemical properties in the arable layer: humus content – 3.08-3.15%, mobile phosphorus – 237-270, and exchangeable potassium – 80-100 mg/kg of soil, pH_{salt} – 5.7, supine saturation of the absorption complex with bases – 85-99%, hydrolytic acidity – 2.1 mg-eq./100 g of soil, density – 1.18 g/cm^3.

Plants officially approved in EU countries by the Register of Regulation 1831/2003 "Feed additives for use in animal feeding" (Community Register, 2003) were selected for study. The accounting area was 10 m^2, repetition – four times. Medicinal and fodder herbs were sown in late March and early April. The seeding rates were as follows: purple coneflower – 10 kg, hyssop – 6 kg, white horehound – 5 kg, fennel – 10 kg, coriander – 10 kg, milk thistle – 11 kg, anise hyssop – 4 kg, St. John's wort – 4 kg, Moldavian dragonhead – 6 kg, sneezeweed – 5 kg, sweet wormwood – 2 kg, yarrow – 3 kg, dandelion – 7 kg/ha of germinating seeds. The method of sowing is wide-row with a row spacing of 45 cm. Sowing was carried out with a manual seed drill.

For growing herbs in clean crops, mineral fertilisers were not applied, as this contradicts the conduct of organic farming. Care for crops on annual crops (milk thistle, coriander, and Moldavian dragonhead) and biannual fennel consisted of 1-2 row-by-row treatments to control weeds. Perennials needed careful care in the year of sowing (one manual weeding and 2-3 row-to-row treatments). In subsequent years, the care of crops in them was similar to annual crops. Weather conditions of growing seasons over the years of research are characterised by a higher 0.9-1.3°C average air temperature and above normal precipitation by 35-70 mm, which was observed mainly in the second half of the growing season.

Harvesting of medicinal and fodder species was carried out in the flowering phase once per growing season, and coriander – in the seed maturation phase. All records and observations of the growth and development of medicinal and fodder herbs were carried out according to the methods of the Institute of Feed and Podillia of NAAS. The dry matter content in the green mass was determined by the thermostatic weight method with drying of samples at 105°C, and the complete zootechnical analysis and digestibility of the feed in vitro and the content of mineral elements in it were determined according to DSTU 4117:2007 by infrared spectrometry with computer support. The content of biologically active substances in air-dry raw materials was carried out according to the methods given in the state pharmacopoeia of Ukraine and in the European Pharmacopoeia (State Pharmacopoeia of Ukraine, 2015; European pharmacopeia: 7.0., 2010). Statistical processing of the obtained results of field experiments was carried out by the method of variance analysis using electronic computing equipment using the Microsoft Excel table processor according to B.A. Dospekhov.

RESULTS AND DISCUSSION

As a result of the conducted research, a list of medicinal and fodder herbs that are most suitable for use as organic feed additives has been established. First of all, this concerns their technological suitability in growing and harvesting raw materials for the creation of phyto-mixtures. Regarding the technological suitability of growing individual medicinal and fodder herbs, it is worth noting that such annual species as milk thistle, Moldavian dragonhead, and coriander do not require significant cultivation costs. It is enough to carry out 1-2 inter-row tillages. The same applies to biannual fennel. As for perennial species: purple coneflower, hyssop, anise hyssop, white horehound, these species require specific care in the year of sowing (manual weeding and 2-3 inter-row treatments to control weeds), and in subsequent years also do not require significant care for crops. The above annual and perennial species are mostly tall (66-155 cm) and are able to compete in crops with weeds.

Phenological observations of the passage of plant growth and development phases and the development of green mowing mass and seeds have established optimal terms of mowing ripeness of certain types of medicinal and fodder herbs. Thus, the harvesting of raw materials in the context of individual types lasts from April to August, which allows its successful implementation and avoiding peaks in the load on the equipment during harvesting and drying of the slope mass.

Studies have also established that the most productive for use as organic feed additives for feeding farm animals are the following species: purple coneflower, hyssop, fennel, milk thistle, anise hyssop, Yarrow, white horehound, dandelion, Moldavian dragonhead, coriander, and other species. The vast majority of them, with the exception of purple coneflower and dandelion, form a yield in the year of sowing, which was 2.8-15.5 t/ha of green mass or 0.7-4.2 t/ha of dry mass. In subsequent years, the most productive among medicinal fodder herbs in terms of green and dry mass yield were milk thistle 14-18 and 3.1-4.2 t/ha, respectively, purple coneflower – 13-20 and 3.3-4.7 t/ha, fennel – 15-21.5 and 3.0-5.0 t/ha, and Moldavian dragonhead –

11-15 and 2.5-4.3 t/ha, and in terms of seed yield – coriander – 0.3-1.8 t/ha. Hyssop, anise hyssop, yarrow, and white horehound are also quite productive. The yield of green and dry mass in the flowering phase in these species reached 8-15 and 1.7-4.8 t/ha, respectively. Purple coneflower, milk thistle, Moldavian dragonhead, and fennel (0.4-0.8 t/ha) are also productive in terms of seed yield (Table 1).

Table 1. *Yield of medicinal and fodder types of herbs, t/ha*

Types of herbs	**Yield**								
Years of research	Green mass			Dry weight			Seeds		
	2020	2021	2022	2020	2021	2022	2020	2021	2021
Purple coneflower *Echinacea purpurea*	13.2	20	13.5	3.3	4.7	3.6	0.22	0.4	0.3
Hyssop *Hyssopus officinalis*	7.5	11	11.3	1.9	4.0	3.8	0.12	0.2	0.2
Fennel *Foeniculum vulgare*	15.0	19	21.5	3.0	4.0	5.0	0.1	0.6	0.6
Coriander *Coriandrum sativum*	9.4	8.4	9.0	1.9	1.6	1.9	0.3	1.8	0.8
Milk thistle *Silybum marianum*	15.5	18	13.8	3.9	4.2	3.1	0.3	0.5	0.2
Anise hyssop *Lophantus anisatus*	2.8	12	15.3	0.7	3.3	4.8	0.02	0.2	0.3
Yarrow *Achilea millefolium*	10.7	14	9.2	2.4	2.7	2.8	0.2	0.2	0.2
White horehound *Marrubium vulgare*	8.5	7	6.0	1.7	2.5	1.6	0.1	0.15	0.1
Dandelion *Taraxacum officinale*	10.7	8	7.3	2.4	1.7	1.5	0.05	0.1	0.1
St. John's wort *Hypericum perforatum*	0.8	3	10.5	0.2	0.7	3.5	-	0.1	0.1
Moldavian dragonhead *Dracocephalum moldavica*	13.8	15	10.8	2.8	4.3	2.5	0.14	0.6	0.3
Sneezeweed *Cephalophora aromatica Schrod.*	1.1	0.7	0.8	0.25	0.2	0.2	0.03	0.02	0.05
Sweet wormwood *Artemisia annua*	0.5	0.3	0.4	0.15	0.1	0.1	0.01	-	0.01
LSD_{05}				0.3	0.78	0.89			

Source*: based on author's research*

Over the years of research, sweet wormwood and sneezeweed remained unclear for obtaining raw materials, the shoots of which were obtained very sparse in the conditions of the dry spring growing season. In addition, the height of these plants is low and they are not able to successfully control weeds in crops, and the use of herbicides in conditions of growing organic raw materials is unacceptable. As for St. John's wort, it formed a satisfactory density only in the third or fourth years of growth. Therefore, these crops are still valuable for obtaining biologically active substances. However, the technologies of their cultivation require thorough improvement.

Evaluating the importance of using medicinal and feed herbs as organic feed additives, it is worth noting that many researchers also consider amino acids, carotene, vitamins, trace elements, etc. to be biologically active substances, including those of non-plant origin, but most of them are normalised by existing animal feeding diets (Petrychenko *et al.,* 2018). According to the research, this complex of biologically active substances primarily includes essential oils (0.1-4.0%), flavonoids and flavonolignans (0.5-3.0%), organic acids, mainly vitamins, polysaccharides (2-8%), and trace elements that provide a positive effect on the animal body. Although the effectiveness of the action of individual components of biologically active substances on the animal body is still poorly understood.

It was found that the aboveground mass of purple coneflower contains up to 7.4% polysaccharides, the sum of chicory and caftaric acids – from 2.2% in the first year of vegetation and up to 4.3% in the third year of vegetation. The content of hydroxycinnamon acid in

purple coneflower raw materials ranges from 2.1% in stems and 4.9 and 6.4% in inflorescences and buds, respectively, in terms of dry matter. The complex of BAS of purple coneflower has a positive effect on metabolism and has an immunostimulating and immunomodulatory effect. The aboveground mass of hyssop contains up to 1.32% essential oil, as well as phenocarbolic acids, including rosmarinic. The complex of biologically active ingredients of hyssop has a positive effect on the gastrointestinal tract and has a sedative effect. Yarrow grass contains from 0.3 to 3.1% essential oil, which contains more than 80 components, and the aboveground part of Moldavian dragonhead – up to 0.33%. The main components of the essential oil of which are citral and geraniol. Essential oil provides anti-inflammatory and antispasmodic effects.

Anise hyssop, in addition to essential oil, contains up to 4% of the amount of flavonoids in terms of luteolin, and white horehound – 2.0-2.8% of the bitter substance marubiin, as well as tannins up to 0.05% and 0.06% of essential oil, which, in addition to a positive effect on the digestive process, increases appetite. Dandelion grass contains sesquiterpene lactones, three terpenes, carotenoids, fatty acids and flavonoids, vitamin A, and inulin. The BAS complex contained in dandelion grass has a significant diuretic effect and improves metabolism. The main components of biologically active substances in fennel is essential oil, the content of which ranges from 2% in the stems to 6.5% in the seeds; in coriander, the content of essential oil in the seeds is 1.5% and fatty oil – 22%; the content of essential oil in Moldavian dragonhead – 0.33%; in sneezeweed – 0.1-0.22%. The dry mass of sweet wormwood also contains 0.5% essential oil and flavonoids, coumarin, etc. Milk thistle is a valuable plant that contains 3% flavonoids, and St. John's wort – flavonoids – 3%, essential oil – 1.25%, tannins – 8%, anthocyanins – 5%.

The authors also determined the content of vitamins in certain types of medicinal and fodder herbs. Thus, the content of vitamin C in purple coneflower and hyssop is 170-250 mg per 100 g of freshly picked raw materials; in fennel, St. John's wort, and coriander – 90-130 mg; in anise hyssop, yarrow, Moldavian dragonhead, dandelion – 30-60 mg per 100 g. The highest carotene content was found in purple coneflower (170 mg per 100 g), slightly lower – in St. John's wort (55 mg), and in other species it was only 5-10 mg per 100 g. Coriander had a high content of rutin (vitamin P) and amounted to 145 mg per 100 g. In other species, it did not exceed 10-15 mg per 100 g. All this complex of biologically active substances, if used in the prescribed doses in animal diets, provides a stimulating effect and the possibility of obtaining organic meat and dairy products.

It is also worth considering that these crops have in their composition not only BAS, but also nutrients inherent in feed species (protein, including amino acids, fat, fibre, without nitrogenous extractives, ash, trace elements, etc.), the chemical composition of which is shown in Table 2. Such types of herbs as anise hyssop, purple coneflower, hyssop, yarrow, dandelion, and Moldavian dragonhead have a high content of crude protein, which is equal to the content of legume species (14.6-18.4%). According to the content of other indicators of complete zootechnical analysis, they and other species under study have a sufficient amount of fibre (22-28%) and BAS (48-53%), and are well provided with potassium, phosphorus and calcium and good digestibility of feed (55.5-63%).

Table 2. *Chemical composition of medicinal and fodder herbs, % for dry matter (average for 2020-2022)*

Types of herbs	Crude protein	Protein	Fat	Fibre	BAS	Ash	Digestibility	K_2O	R_2O_5	CaO
Anise hyssop	14.6	13.6	2.74	23.71	50.5	8.52	59.65	2.67	0.81	1.57
Purple coneflower	16.1	14.7	2.43	21.84	50.9	8.69	63.3	2.77	0.88	1.69
Hyssop	14.9	13.8	3.01	21.49	52.9	7.81	64.1	2.78	0.86	1.45
Coriander	14.4	12.7	3.78	25.62	47.4	8.50	60.9	3.06	0.80	1.66
Milk thistle	12.0	10.9	2.53	28.80	48.4	8.35	54.4	2.52	0.86	1.88
Yarrow	15.8	14.4	2.40	23.46	49.7	8.71	62.1	2.83	0.85	1.41
Fennel	11.6	10.4	2.65	27.20	49.9	8.71	57.9	2.89	0.82	1.63
Dandelion	18.4	16.9	2.03	23.10	48.0	8.48	68.9	2.51	0.86	1.34
St. John's wort	13.2	12.5	2.7	24.2	53.0	6.9	55.5	2.0	0.67	1.4
Moldavian dragonhead	16.4	15.0	2.6	23.2	50.4	8.85	62.8	2.9	0.82	1.5
White horehound	12.6	11.2	2.51	25.3	51.2	8.43	52.1	2.41	0.80	1.43

Source: *based on author's research*

These data on the chemical composition indicate that medicinal and fodder species are equated with cereals and legumes in terms of nutritional value, and when feeding livestock, their nutritional value should be considered in diets. Thus, the presented experimental data show the high value and prospects of use in feed production, due to the content of biologically active substances in them and their technological suitability in the preparation of raw materials, such medicinal feed species: purple coneflower, hyssop, fennel, milk thistle, anise hyssop, Yarrow, white horehound, dandelion, Moldavian dragonhead, coriander.

The uniqueness of these studies lies in the fact that the methodological basis for the use of medicinal and fodder herbs in feed production for the first time is based on the principle that medicinal herbs, when used in established doses in veterinary medicine, provide a therapeutic effect (Paskudska *et al.,* 2018; Moisiienko, 2020), and when these doses are reduced, the stimulating effect (Palapa *et al.,* 2016; Zubova, 2021). In particular, the authors' studies have shown a positive effect of phyto-mixtures formed from certain types of medicinal and fodder herbs on the productivity of a dairy herd of cattle (Shtakal *et al.,* 2022). Therefore, solving the problems of creating sown phytocenoses based on medicinal and feed species with the content of biologically active substances and the development of phyto-mixtures from them is a promising area of research in feed production, since their use increases the productivity of animal husbandry and is able to ensure the production of organic meat and dairy products. In EU countries and in Ukraine, hundreds of plant species are used in veterinary medicine (Vlizlo *et al.,* 2018; Karomatov *et al.,* 2019; Salomon *et al.,* 2019). In addition, the experimental station of medicinal plants of the Institute of Agroecology of NAAS has developed technologies for growing the vast majority of these crops for use in veterinary medicine (Pryvedenyuk *et al.,* 2020). Separate studies on the cultivation of fennel were conducted at the Zhytomyr National Agroecological University of the Ministry of Education and Science of Ukraine (Moisiienko *et al.,* 2019) and chamomile at Kamianets-Podilsky State Agrarian and Technical University of the Ministry of Education and Science of Ukraine (Padalko *et al.,* 2021). However, these studies did not aim to grow medicinal and fodder herbs on a large scale, using phyto-mixtures as feed additives specifically for establishing their technological suitability for this purpose. In addition, the uniqueness of this study lies in the fact that for the first time, the chemical composition and nutritional value of medicinal and fodder herbs are presented, including the content of active substances in them, that is, biologically active substances, namely: polysaccharides, essential oils, flavonoids, vitamins, tannins, anthocyanins, bitterness, etc.

Research on the use of medicinal and fodder herbs as feed additives is extremely limited, which is explained by the originality of their use for this purpose. However, some studies have shown the prospects of this area of research. In particular, at the Vinnytsia National Agrarian University (Chudak *et al.,* 2020) the effectiveness of using pale purple coneflower on poultry (quails) has been proven. Previous publications indicate the effectiveness of using purple coneflower on pigs at the Institute of Pig Breeding of NAAS and on fish at the Institute of Fisheries of NAAS, as well as milk thistle for feeding turkeys and piglets.

That is, these studies have considered the value for feed production not only of certain types of medicinal and fodder herbs for certain types of livestock, but also a fairly wide range of medicinal and fodder herbs (purple coneflower, hyssop, white horehound, fennel, anise hyssop, milk thistle, coriander, St. John's wort, yarrow, dandelion, Moldavian dragonhead), established the content of biologically active substances in them and their technological suitability for mechanised harvesting. Summarising the literature data on the solution of such an important national economic problem as increasing the productivity of livestock and poultry and obtaining organic livestock products from it, it becomes clear that such data are not enough in the modern literature in the region. In particular, it requires a deep study of both the positive effect on the animal body of certain types of medicinal and fodder herbs, and phyto-mixtures, as well as the effect of individual biologically active substances of plants. Therefore, this paper is actually the first attempt to solve this problem. All this encourages joint actions of specialists in feed production and animal feeding to successfully solve this problem. As a result, it would be possible to introduce medicinal and fodder herbs into production to replace existing feed additives (premixes) in the production of pure organic products of animal origin for the health of the nation.

CONCLUSIONS

Promising types of medicinal and fodder herbs with the content of biologically active substances for animal feeding as organic feed additives can be hyssop, fennel, white horehound, Moldavian dragonhead, coriander, yarrow, purple coneflower, milk thistle. They are technologically suitable for harvesting and provided the yield of annuals (coriander, milk thistle, Moldavian dragonhead) in the year of sowing 2.5-4.3 t/ha of dry weight and 0.3-1.8 t/ha of seeds, and in the second and subsequent years of use of herbage and perennials (purple coneflower, hyssop, white horehound, fennel, anise hyssop, yarrow) respectively – 2.5-5.0 t/ha of dry weight and seeds 0.2-1.8 t/ha.

The value of medicinal herbs that can be used for feeding animals lies in the content of such biologically active substances in them: in purple coneflower – polysaccharides (2-8%), vitamin C – 250 mg, and carotene – 170 mg per 100 g of freshly picked raw materials;

hyssop – essential oils – 1.32% and vatamine C – 170 mg per 100 g; milk thistle – flavonoids – 3%; anise hyssop – flavonoids – 4%; yarrow – essential oils – 0.3-3.1%; Moldavian dragonhead – essential oils – 0.33%; St. John's wort – flavonoids – 3% and essential oil – 1.25%; white horehound – 2-2.8% marubin; fennel – essential oils – 2-6.5%; coriander seed – essential oils – 1.5% and rutin content – 145 mg per 100 g; sweet wormwood – essential oils – 0.5%, sneezeweed – essential oils – 0.1-0.22%; dandelion – vitamin C content – 30-60 mg per 100 g of raw materials, flavonoids, sesquiterpenes.

Medicinal and fodder types of herbs have a sufficient amount of fibre for animals (22-28%) and BAS (48-53%) and are well provided with potassium, phosphorus, and calcium, and such species as anise hyssop, purple coneflower, hyssop, yarrow, dandelion, Moldavian dragonhead also have a high content of crude protein, which is equal to the content of legumes (14.6-18.4%), which should be considered when creating animal feeding rations. As raw materials for the production of biologically active substances, such crops as sweet wormwood, sneezeweed, and St. John's wort have shown low prospects when used in organic feed production, and the technologies of their cultivation and mechanised harvesting of raw materials require additional study.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

None.

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Господарсько-біологічна цінність лікарсько-кормових трав для кормовиробництва

Микола Іванович Штакал

Доктор сільськогосподарських наук, старший науковий співробітник
ННЦ «Інститут землеробства НААН»
08162, вул. Машинобудівників, 2-б, смт. Чабани, Україна
https://orcid.org/0000-0002-9511-0290

Микола Адамович Ткаченко

Доктор сільськогосподарських наук, член-кореспондент НААН
ННЦ «Інститут землеробства НААН»
08162, вул. Машинобудівників, 2-б, смт. Чабани, Україна
https://orcid.org/0000-0001-6128-4703

Лариса Петрівна Коломієць

Кандидат сільськогосподарських наук, старший науковий співробітник
ННЦ «Інститут землеробства НААН»
08162, вул. Машинобудівників, 2-б, смт. Чабани, Україна
https://orcid.org/0000-0003-3408-8541

Любов Миколаївна Голик

Кандидат сільськогосподарських наук, старший науковий співробітник
ННЦ «Інститут землеробства НААН»
08162, вул. Машинобудівників, 2-б, смт. Чабани, Україна
https://orcid.org/0000-0002-7157-6520

Олексій Васильович Устименко

Кандидат сільськогосподарських наук, старший науковий співробітник
Дослідна станція лікарських рослин Інституту агроекології і природокористування НААН
37535, вул. Покровська, 16-а, с. Березоточа, Україна
https://orcid.org/0000-0002-5321-6812

Анотація. Актуальність проведених досліджень полягає в необхідності залучення в кормо виробництво видів трав з вмістом біологічно активних речовин для використання їх в якості природних стимуляторів росту тварин. Метою досліджень було експериментально встановити господарсько-біологічну цінність видів лікарсько-кормових трав, їх технологічну придатність за вирощування в чистих посівах, отримання сировини та формування з неї фіто сумішей для використання в якості органічних кормових добавок**.** В процесі проведення досліджень були використані наступні методи – польовий, лабораторний, аналітичний, статистичний. Було визначено господарсько-біологічну цінність для виростання в кормо виробництві таких видів лікарсько-кормових трав: гісоп лікарський, фенхель звичайний, шандра звичайна, змієголовник молдавський, коріандр посівний, деревій звичайний, ехінацея пурпурова, кульбаба лікарська, розторопша плямиста, лофант анісовий, звіробій звичайний, цефалофлора ароматна, полин однорічний. Встановлено, що однорічники в рік посіву, а багаторічні види на другий-четвертий роки користування забезпечували отримання сухої маси трав – 1,7-5,0 т/га та насіння – 0,3-1,8 т/га. Дані види трав мають в своєму складі біологічно активні речовини (полісахариди, ефірні масла, флавоноїди, органічні кислоти, переважно вітаміни, мікроелементи), що позитивно впливають на тваринний організм. Доведено також технологічну придатність для заготівлі сировини і формування фіто сумішей таких видів: розторопша плямиста, змієголовник молдавський, коріандр посівний, гісоп лікарський, фенхель звичайний, ехінацея пурпурова, лафант анісовий, шандра звичайна, деревій звичайний. В результаті досліджень створена база даних щодо добору лікарсько-комових трав, їх технологічної придатності вирощування, оптимальних строків збирання для заготівлі сировини з наступним використанням у кормо виробництві. Включення лікарсько-кормових видів в раціони годівлі може забезпечувати отримання органічної продукції тваринництва, що відповідає вимогам стратегії Європейського зеленого курсу

Ключові слова: лікарсько-кормові види; урожайність; хімічний склад; технологічна придатність; фітосуміші; біологічно активні речовини; сировина; строки збирання

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 26(7), 54-65

UDC 633.522:631.5:631.427
DOI: 10.48077/scihor7.2023.54

Features of forming the productivity of modern hemp varieties using organic cultivation technology

Andriy Pylypchenko
Postgraduate Student
Poltava State Agrarian Academy
36003, 1/3 Skovorody Str., Poltava, Ukraine
https://orcid.org/0000-0003-2044-8948
Mykola Marenych
Doctor of Agriculture Sciences, Professor
Poltava State Agrarian Academy
36003, 1/3 Skovorody Str., Poltava, Ukraine
https://orcid.org/0000-0002-8903-3807
Volodymyr Hanhur
Doctor of Agriculture Sciences, Senior Research Fellow
Poltava State Agrarian Academy
36003, 1/3 Skovorody Str., Poltava, Ukraine
https://orcid.org/0000-0002-5619-492X
Tetiana Tymoshchuk*
PhD in Agricultural Sciences, Associate Professor
Polissia National University
10008, 7 Staryi Blvd., Zhytomyr, Ukraine
https://orcid.org/0000-0001-8980-7334
Lesia Malynka
PhD in Agricultural Sciences
Scientific and Methodological Center of Higher and Professional Higher Education
03158, 11 Smilyanska Str., Kyiv, Ukraine
https://orcid.org/0000-0001-8307-6681

Article's History:
Received: 24.04.2023
Revised: 24.06.2023
Accepted: 9.07.2023

Abstract. Seed hemp can be used to produce products and restore soil fertility. The adaptive potential of cannabis varieties can be implemented by optimising their cultivation technologies. The purpose of this study was to substantiate the features of forming the productivity of cannabis varieties adapted to organic cultivation technologies. Field studies were conducted during 2019-2021 on leached chernozems. Research methods: field, laboratory, statistical and comparative calculation. The regularities of yield formation of hemp straws, fibre, and seeds depending on the

Suggested Citation:
Pylypchenko, A., Marenych, M., Hanhur, V., Tymoshchuk, T., & Malynka, L. (2023). Features of forming the productivity of modern hemp varieties using organic cultivation technology. *Scientific Horizons*, 26(7), 54-65. doi: 10.48077/scihor7.2023.54.

*Corresponding author

genetic potential of varieties and cultivation technology were investigated. The suitability of five hemp varieties for organic cultivation was evaluated. It was established that the introduction of organic cultivation technology has a positive effect on crop productivity. With organic cultivation of Hliana and Hloba varieties, the increase in the yield of straw (0.07-0.11 t/ha) was statistically insignificant compared to inorganic technology. Cultivation of Zolotoniski 15 and Sula varieties using organic technologies increased the yield of hemp straw by 0.14 t/ha. The Lara variety showed an insignificant decrease in the straw yield. This confirmed the theory that the introduction of organic cultivation of hemp will not lead to a decrease in yields. Organic technologies for growing hemp contributed to an increase in their yield compared to the traditional one, provided that varieties were selected correctly. The best suitability for organic cultivation in terms of fibre yield was recorded in the Lara variety. The obtained results will be used to improve and introduce organic technologies for growing adapted hemp varieties, depending on the purpose of fibre or seeds

Keywords: seeds, straw; fibre; genetic potential; biodestructor; correlation

INTRODUCTION

Agribusiness around the world is interested in cannabis, as its cultivation and processing can significantly contribute to the European Union's bioeconomy strategy. Market interest in growing this niche crop encourages a gradual transition from the traditional use of stem fibres (textiles, cellulose or paper) to multi-purpose production. Hemp (*Cannabis sativa* L.) is a valuable high-yielding annual crop, because due to its unique consumer properties, all parts of the plant are used in different ways. Many types of products are made from the plant material of this crop. Due to the lack of investment in research over decades, restrictions have led to the need to develop sustainable hemp production systems.

Strategic areas for the development of the agricultural sector are the cultivation of highly profitable niche crops. The adaptive productivity potential of niche crop varieties can be implemented by optimising the elements of their cultivation technologies (Kyrylyuk *et al.,* 2019; Panchyshyn *et al.,* 2023). It is advisable to consider the scientific developments of researchers to improve the yield and quality of crop production.

In many European countries, cannabis varieties are grown that are suitable for multiple uses, including fibre and seed (Tang *et al.,* 2016). An important area of use of hemp in addition to food is energy – for the production of bioethanol, biogas, and biodiesel (Viswanathan *et al.*, 2021). C. Asquer *et al.* (2019) confirmed the possibility of using industrial hemp straw residues in the biogas sector for biogas production by anaerobic digestion. Research has shown that the essential oil obtained from industrial hemp can be used as biological insecticides, acaricides or repellents to protect plants from pests in organic production (Rossi *et al.,* 2020). According to G. Benelli *et al.* (2018), the strengths of growing cannabis for the production of bioinsecticides include the following: low costs for the production of raw materials and the availability of land for growing crops, increased demand for environmentally safe products, the possibility of using by-products in other industries, in particular cosmetics and pharmaceuticals.

It does not require the use of plant protection products or pesticides, and hemp itself suppresses weeds, repels pests, is resistant to pathogens and requires only minerals contained in the soil. This has a positive effect on the environment, as it contributes to the preservation of soil fertility (Adesina *et al.,* 2020). Hemp can be grown for several years in a monoculture without reducing the yield, it is a good precursor for the most important crop – wheat (Gorchs *et al.,* 2017). However, it has been established that growing hemp in a monoculture can lead to a deterioration in soil fertility. According to V.M. Kabanets and S.I. Berdin (2020) growing this crop in a monoculture without the use of fertilisers leads to a significant decrease in the content of humus and basic nutrients in the arable soil layer.

Studying the productivity of modern hemp varieties to determine their adaptability in specific environmental conditions is an important factor in harnessing their genetic potential and increasing profitability (Cherney & Small, 2016). Researchers in Serbia conducted studies to evaluate different varieties of cannabis by plant height, stem yield, fibre and seed yield (Habán *et al.,* 2022). It was found that dicotyledonous varieties were preferred for the conditions of Southern and South-Eastern Europe for the production of biomass (stems and fibres), and monoecious varieties were preferred for seed production. According to researchers, an important factor in successful cannabis cultivation is to consider the climatic conditions of the environment and adapt agricultural technologies to ensure optimal conditions for plant growth and development. The adaptive potential of modern cannabis varieties can be maximised by optimising agricultural technologies, in particular, the transition to organic production. In modern market conditions, the eco-brand is one of the main prerequisites for effective economic development of the country. Currently, the level of environmental safety of goods in the international market is one of the main factors determining their competitiveness (Berezovsky, 2020). The growing demand of consumers for innovative products made from safe plant

raw materials may become a prerequisite for expanding the production of hemp.

The solution to the problem of growing hemp is now becoming relevant and requires optimisation of cultivation technology. Therefore, the purpose of the study was to establish the features of forming the productivity of hemp crops depending on varietal characteristics and cultivation technology.

MATERIALS AND METHODS

The study was conducted during 2019-2021 on leached chernozems in forest-steppe conditions.

The experiment scheme includes factors: Factor A – conditions of years of research. Factor B – varieties: 1. Hliana (Standard); 2. Zolotoniski 15; 3. Lara; 4. Hloba; 5. Sula. Factor C – cultivation technology: 1. inorganic (control); 2. transitional; 3. organic; 4. organic + BioStimix-Niva, 1 l/ha (in the phase of 3 pairs of leaves).

The originator of the Sula, Hloba, Lara varieties is LLC "Institute of organic farming", and the Hliana and Zolotoniski 15 varieties – Institute of Bast Crops of NAAS,

The soil of the experimental plots at a 0-20 cm depth was characterised by the following agrochemical indicators: pH-salt – 6.6, humus content – 4.16%, easily hydrolysed nitrogen – 124.6 mg/kg of dry soil, mobile forms of phosphorus – 140.3 mg/kg of dry soil, exchange potassium – 87.7 mg/kg of dry soil. The depth of the humus horizon is 53-100 cm. The predecessor of hemp in the crop rotation was soybeans. Sowing of hemp was carried out with a Monosem seed drill. The seeding rate of hemp varieties for dual use (seeds and fibre) was 1.2 million pcs./ha of germinating seeds, and for green fibre – 4.0 million pcs./ha of germinating seeds. The total area of the experiment was 0.68 hectares. The accounting plot area – 25 m². The repetition rate in the experiment is fourfold. Inorganic cultivation technology provided only for the use of mineral fertilisers $N_{30}P_{30}K_{30}$ without the use of plant protection products. Mineral fertilisers were not used in the variants with transitional and organic technology. The microbiological preparation BioStimix-Niva was applied in the phase of three pairs of leaves with a consumption rate of 1 l/ha.

The analysis of the yield of the Lara variety using various cultivation technologies was carried out according to the scheme: 1. Hliana (control); 2. Lara (inorganic); 3. Lara (organic); 4. Lara (organic + BioStimix-Niva application, 1 l/ha).

The predecessor of hemp was soybeans. The soil of the experimental plots is leached chernosem, characterised by the following indicators in the 0-20 cm layer: pH – 6.4, humus content – 4.01%, easily hydrolysed nitrogen – 114.8 mg/kg dry soil, mobile forms of phosphorus – 138.3 mg/kg dry soil, exchange potassium – 89.8 mg/kg dry soil. Accounting of the yield of straw, fibres, and seeds was carried out according to conventional methods. The obtained research results were processed statistically using Excel and Statistica 10.0 software suites. A comparison of the significant difference between the average values was made using the criterion of the least significant difference. The significance level was set to $P \leqslant 0.05$.

RESULTS

The creation of new hemp varieties sets the task of finding ways to optimise cultivation technologies to ensure the realisation of their genetic potential. The yield of hemp fibre had the characteristics of its variation. The best indicator was observed in the Lara variety, which averaged 3.6 t/ha over the years of research (Fig. 1).

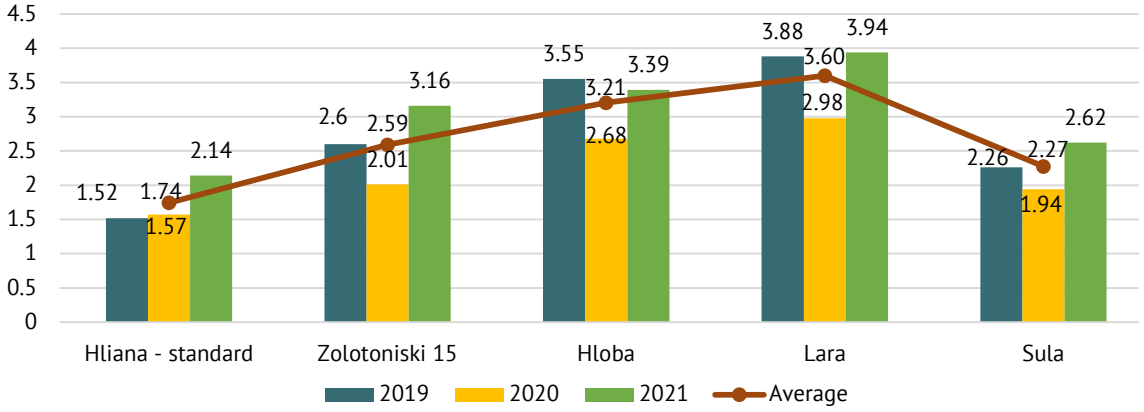

Figure 1. *Yield of hemp fibre in variety testing crops, 2019-2021*

The lowest yield of hemp fibre over the years of research was in the Hliana variety – 1.74 t/ha. The highest fibre yield (3.05 t/ha) on average for varieties was noted in 2021. The worst year for the formation of fibre yield was 2020. The average yield for varieties this year was 2.24 t/ha. In 2019, the highest fibre yield was found in the Lara variety (3.88 t/ha), which is 2.6 times higher than the yield of the Hliana variety (1.52 t/ha). In 2019, the yield of fibre of Lara was 0.33-1.62 t/ha higher than that of Sula, Zolotoniski 15 and Hloba varieties. Of all

the varieties selected by the Institute of organic agriculture, the lowest fibre yield was demonstrated by the Sula variety (2.26 t/ha), which is 0.74 t/ha more compared to the Hliana variety (standard). The fibre yield of the Sula variety was 1.62 t/ha lower compared to the Lara variety. The highest yield of hemp fibre in 2021 was formed by the Lara variety – 3.94 t/ha, which is 1.84 t/ha more compared to the Hliana variety (standard). This year, the yield of hemp fibre in the Sula variety was 1.32 t/ha less than the Lara variety and 0.48 t/ha more than the Hliana variety. The yield of fibre of Zolotoniski 15 and Hloba varieties exceeded the Hliana variety (standard) by 1.8-1.25 t/ha. The least favourable year for the formation of the yield of hemp fibre was 2020. The yield of fibre of all varieties decreased. The most sensitive varieties to the conditions of the year were Sula and Hliana. The yield of these varieties was lower by 1.04 and 1.41 t/ha, respectively, compared to the Lara variety. Such variability in the yield of hemp fibre indicates the feasibility of growing several varieties at the same time. It is best to use the Hloba, Lara, and Sula varieties for this purpose.

Organic technology of growing hemp straws and fibres contributed to an increase in yield (Table 1).

Table 1. *Formation of yield straw and fibres depending on the conditions of years of research (factor A), variety, and cultivation technology (2019-2021)*

Variety (factor *B*)	Growing technology (factor *C*)	Yield, t/ha	
		straw	fibres
Hliana – standard	inorganic (control)	4.09	1.74
	transitional period	4.16	1.74
	organic	4.16	1.80
	organic + BioStimix-Niva, 1 l/ha	4.20	1.81
Zolotoniski 15	inorganic (control)	4.73	2.62
	transitional period	4.47	2.62
	organic	4.72	2.65
	organic + BioStimix-Niva, 1 l/ha	4.87	2.67
Lara	inorganic (control)	5.05	3.58
	transitional period	4.97	3.60
	organic	5.00	3.64
	organic + BioStimix-Niva, 1 l/ha	4.96	3.66
Hloba	inorganic (control)	5.11	3.19
	transitional period	5.00	3.21
	organic	5.13	3.24
	organic + BioStimix-Niva, 1 l/ha	5.21	3.25
Sula	inorganic (control)	5.19	2.73
	transitional period	5.28	2.72
	organic	5.18	2.75
	organic + BioStimix-Niva, 1 l/ha	5.33	2.77
	LSD_{05} *A*	-	0.01
	LSD_{05} *B*	0.06	0.01
	LSD_{05} *C*	0.05	0.01
	LSD_{05} *AB*	0.11	0.02
	LSD_{05} *BC*	0.12	-

Source: *compiled by the authors*

The yield of hemp straws of varieties Hliana and Hloba increased slightly in variants with organic cultivation. The increase in the yield of these varieties was 0.7-0.11 t/ha compared to the control, which is within a significant difference. This indicates an insignificant increase in the yield of straw using organic technology compared to the control (inorganic). Using organic cultivation technology, Zolotoniski 15 and Sula varieties increased the yield of straw by 0.14 t/ha compared to the control. Growing the Lara variety using organic technologies led to a certain decrease in yield, although the difference did not exceed the LSD criterion. Therefore, it cannot be said that the introduction of organic cultivation technology will inevitably lead to a decrease in yield.

The average yield of the straw of the varieties under study with inorganic cultivation technology was 4.83 t/ha, transitional – 4.78 t/ha, organic – 4.84 t/ha. Cultivation of hemp varieties using organic technology using the BioStimix-Niva destructor ensured the formation of an average yield of 4.91 t/ha. There is an average direct correlation between the yield of straw and hemp fibre (r=0.56), which significantly determines the influence of varietal properties (factor B) and cultivation technology (factor C) on this indicator. In general, there was a positive reaction of fibre yield to the use of organic technologies, which is especially important for obtaining a gross indicator. In the future, the authors will consider the system of relationships between seed yield, which also has correlations with indicators of vegetative mass.

The average fibre yield of Hliana variety was 1.77 t/ha, Zolotoniski 15 variety – 2.64 t/ha, Lara variety – 3.62 t/ha, Hloba variety – 3.22 t/ha, and Sula variety – 2.74 t/ha. According to this indicator, the best suitability for growing using organic technologies was observed in the Lara variety. The yield of fibre using inorganic and transitional cultivation technologies is at the same level and averages 2.77 and 2.78 t/ha, respectively. According to organic cultivation technologies, the fibre yield is 2.82-2.83 t/ha. Thus, the use of a biodestructor did not significantly affect this indicator. The highest fibre yield was obtained when growing the Lara variety (3.58-3.66 t/ha). The lowest yield of hemp fibre was recorded in the Hliana variety – 1.74-1.81 t/ha.

The yield of straw and hemp fibres is characterised primarily by dependence on varietal properties (Fig. 2).

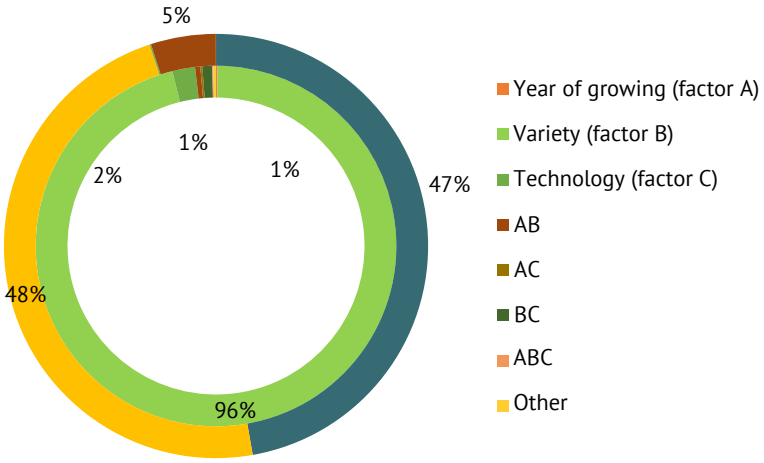

Figure 2. *Shares of influence of factors and their interactions on the yield of hemp straw (outer circle) and fibre (inner circle)*

However, there is a certain difference between these indicators – the yield of straw has an insignificant dependence on the conditions of the year, in contrast to the yield of fibre. The conditions of years of research had a more significant impact on the formation of fibre yield (47%). The genetic properties of the variety (factor B) had a dominant influence on the yield of the hemp straw, with a 96% share of influence. The influence of cultivation technology and the interaction of factors does not exceed 4%. The influence of the variety on the formation of fibre yield was 48%, that is, almost half.

Average yield indicators of straw, depending on the cultivation technology, also convincingly demonstrate that with organic hemp production, crops can exceed the usual yield, provided that the varieties are correctly selected. As a result of the study, it was found that the correct choice of hemp varieties can provide an increase in the yield of straw using organic technologies compared to traditional ones (Fig. 3).

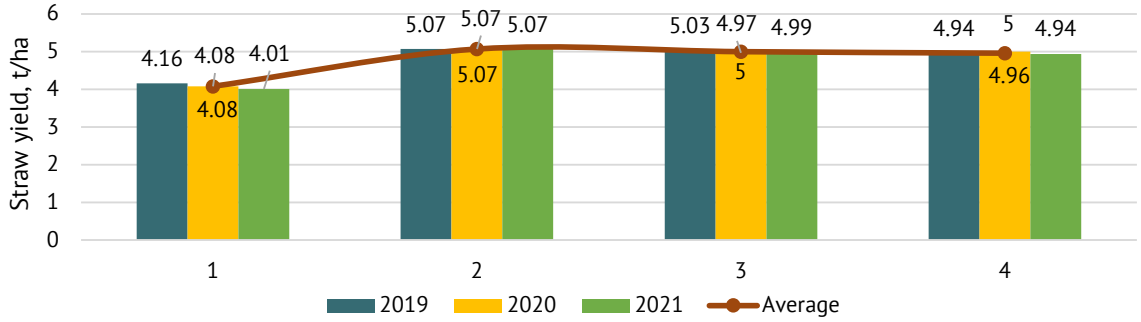

Figure 3. *Yield of straw depending on the varieties and cultivation technology (LSD_{05} by technology factor – 0.10 t/ha)*
Note: *1 – Hliana (control); 2 – Lara (traditional); 3 – Lara (organic); 4 – Lara (organic + application of BioStimix-Niva, 1 l/ha)*

On average, over three years of research, the Hliana variety showed a stable yield of straw at the level of 4.08 t/ha, which is 0.99 t/ha less than the Lara variety. The yield of straw of the Lara variety over the years of research ranged from 4.94 to 5.07 t/ha, depending on the cultivation technology. Therefore, to obtain the maximum yield of hemp products, it is necessary to carefully select varieties according to the area of use. Growing hemp of the Lara variety using various organic technologies provides an average yield of 4.96 and 5.0 t/ha over the years of research, which is 0.07 and 0.11 t/ha less compared to the classical technology. Such a decrease in the yield of hemp straw of the Lara variety is insignificant.

Analysis of the seed yield of the varieties studied in the variety testing also showed that the highest indicators were formed in the Sula variety (Fig. 4).

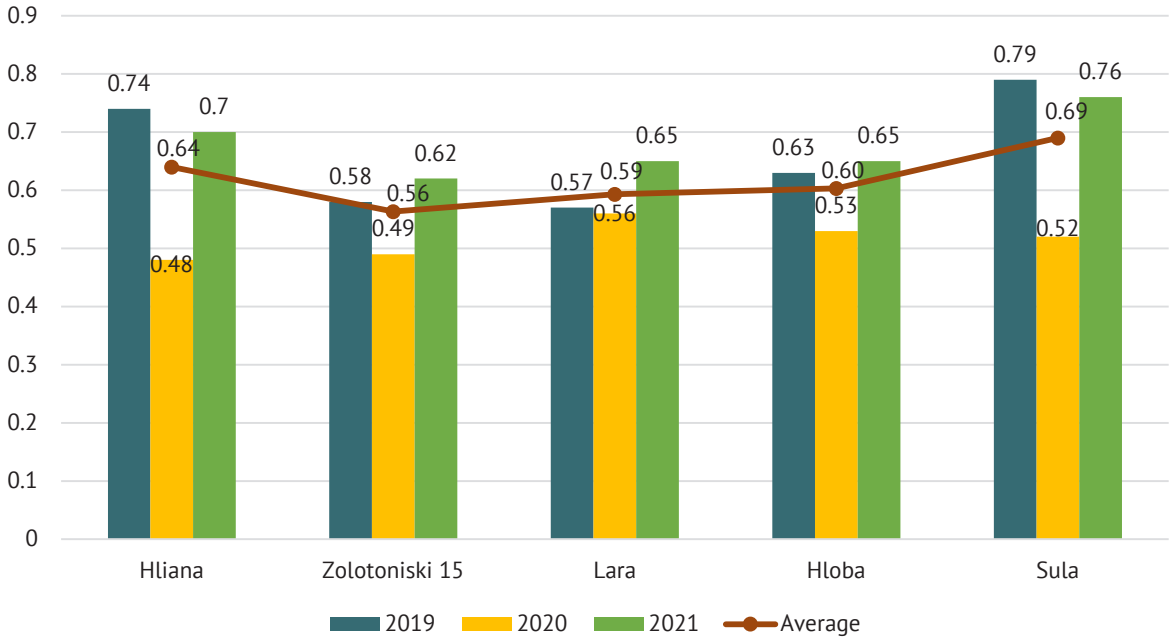

Figure 4. *Yield of hemp seeds in variety testing, 2019-2021*

The highest yield of hemp seeds was obtained in 2019 and 2021. In 2020, the seed yield was slightly lower. The yield of the Hliana variety was 0.4-0.6 t/ha lower compared to the Sula variety. In the Zolotoniski 15, Lara, and Hloba varieties, the average seed yield was 0.04-0.08 t/ha lower compared to the Hliana variety. The dependence of the yield on varietal characteristics and conditions of the research year confirms the feasibility of growing 3-4 hemp varieties on the farm annually to obtain stable yields.

The yield of hemp seeds had a slight variation in the variants of experiments. This allowed identifying the main factors influencing the formation of seed yield and proving the effectiveness of organic cultivation technologies.

Despite the fact that the average seed yield over the years of research had insignificant intervals of variation (0.56-0.58 t/ha), the conditions of the years have a significant impact on it (Fig. 5).

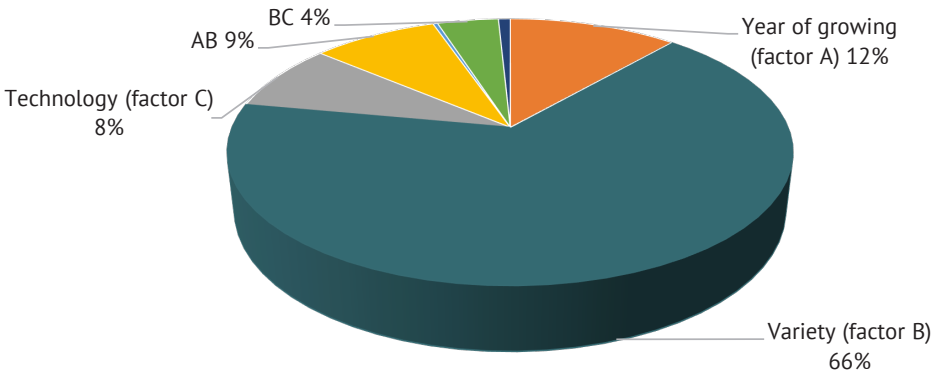

Figure 5. *Shares of influence of growing factors on the yield of hemp seeds*

The share of influence of cultivation technologies (factor C) was less significant on the formation of the yield of hemp seeds (8%). This indicates the prospect of using organic technologies for growing hemp. At the same time, there are opportunities to improve organic cultivation technologies to obtain a high level of yield. According to the results of research, it was found that varietal properties have the greatest influence on yield (66%). It is the variety that plays a crucial role in the formation of crop yield indicators. The influence of cultivation technologies also plays an important role in the complex of factors and interactions that affect seed yield (Table 2).

Table 2. *Yield of hemp seeds depending on varietal characteristics, cultivation technology, and year of research (factor A)*

Varieties (factor *B*)	Technology (factor C)	Yield, t/ha			
		2019	2020	2021	Average
Hliana – standard	inorganic (control)	0.62	0.55	0.54	0.57
	transitional period	0.62	0.52	0.53	0.56
	organic	0.60	0.55	0.52	0.56
	organic + BioStimix-Niva, 1 l/ha	0.62	0.60	0.56	0.59
Zolotoniski 15	inorganic (control)	0.54	0.53	0.54	0.54
	transitional period	0.54	0.55	0.53	0.54
	organic	0.54	0.54	0.53	0.54
	organic + BioStimix-Niva, 1 l/ha	0.53	0.54	0.54	0.54
Lara	inorganic (control)	0.55	0.56	0.55	0.55
	transitional period	0.56	0.55	0.55	0.55
	organic	0.54	0.54	0.54	0.54
	organic + BioStimix-Niva, 1 l/ha	0.56	0.56	0.56	0.56
Hloba	inorganic (control)	0.55	0.55	0.56	0.55
	transitional period	0.56	0.55	0.56	0.56
	organic	0.60	0.55	0.60	0.58
	organic + BioStimix-Niva, 1 l/ha	0.63	0.60	0.60	0.61
Sula	inorganic (control)	0.60	0.60	0.60	0.60
	transitional period	0.64	0.62	0.62	0.63
	organic	0.62	0.62	0.61	0.62
	organic + BioStimix-Niva, 1 l/ha	0.61	0.61	0.61	0.61
LSD_{05} (factor *A*)					0.01
LSD_{05} (factor *B*)					0.01
LSD_{05} (factor *C*)					0.01
LSD_{05} (*AB*)					0.02
LSD_{05} (*BC*)					0.02

Source: *compiled by the authors*

In 2019, the highest yield indicator was recorded in the Sula variety using transitional cultivation technology. Slightly lower seed yields were obtained using organic cultivation technologies, although this deviation was within the statistical error range. Zolotoniski 15 and Lara varieties had the lowest seed yields, which did not exceed 0.54 and 0.56 t/ha, respectively. This year, the greatest variation in yield was observed – 0.53-0.64 t/ha. In subsequent years, the yield of hemp seeds in all variants of the experiment varied from 0.52 to 0.62 t/ha. The best response to the use of organic technology was the Hloba variety, where the yield increase is up to 10%. It is noteworthy that the use of a biodestructor led to a certain increase in yield, which was noticeable in the Hliana variety – 3.5%, and in the Hloba variety – 9.8% compared to the control variants.

The results of the analysis of the yield of hemp seeds of the Lara variety depending on the cultivation technology are shown in Figure 6.

Figure 6. *Yield of hemp seeds depending on the cultivation technology, 2019-2021*
Note: *1 – Hliana (control); 2 – Lara (traditional); 3 – Lara (organic); 4 – Lara (organic + application of BioStimix-Niva, 1 l/ha)*

The highest yield of hemp seeds of the Hliana variety was observed using inorganic cultivation technology in 2019. On average, over the years of research, deviations in the yield of the Lara variety were insignificant. As a result, the study of experimental data by multivariate analysis of variance did not establish the influence of the studied factors. A detailed correlation analysis of economically valuable traits confirmed the hypothesis that the number of correlations may be different for each variety (Table 3).

Table 3. *Correlation coefficients r between economically valuable characteristics of hemp varieties*

Indicators	Varieties				
	Hliana	Zolotoniski 15	Lara	Hloba	Sula
Height of plants during biological ripeness, cm	***0.52***	0.11	0.02	***0.41***	-0.06
Duration to biological ripeness, days	-0.01	0.18	0.11	***0.42***	-0.14
Height of plants during harvesting on straw, cm	***0.60***	0.01	0.06	0.13	-0.04
Yield of straw, t/ha	***0.38***	-0.15	-0.14	***0.43***	-0.05
Seed yield, c/ha	1.00	1.00	1.00	1.00	1.00
Oil content, %	***-0.61***	0.11	0.05	***-0.46***	-0.16
Fibre yield, t/ha	***-0.45***	-0.08	0.01	***0.32***	-0.04
Fibre content in stems, %	***-0.73***	-0.07	0.02	0.18	0.08

Source: *compiled by the authors*

The Hliana variety had correlations between seed yield and plant height during the period of biological ripeness, the period of harvesting, and the yield of straw. In this variety, inverse correlations with oil content, fibre yield, and fibre content were also tracked. Of all the correlations, only one was strong – with the fibre content in the stems. Therefore, it is more appropriate to use the Hliana variety for growing fibre, rather than for seed production or dual-use. Although in the conducted studies, the varieties selected by LLC "Institute of organic farming" showed significantly better results compared to the varieties Hliana and Zolotoniski 15.

DISCUSSION

Many researchers have investigated the effectiveness of implementing crop cultivation technologies for the production of organic goods (Gerasko *et al.,* 2022; Kolomiyets *et al.,* 2022). According to Gerasko *et al.* (2022), an important task of organic production is to increase the volume of safe crops and maintain the stability of agroecosystems. B.N. Nasiyev *et al.* (2022) highlighted the relevance of a biological technology for growing crops such as barley and safflower for effective management of the agricultural landscape in organic farming. Cannabis, due to its unique properties, is a versatile and sustainable crop. In the course of research, it was found that its cultivation can minimise the use of synthetic fertilisers, since it requires minimal use of them. Growing hemp also helps minimise the environmental impact of carbon (Nath, 2022). The beneficial environmental impact of cannabis on the environment can reduce the cost of its protection measures to some

extent. As indicated by Żuk-Gołaszewska *et al.* (2018), one hectare of cannabis is capable of absorbing about 2.5 tonnes of carbon dioxide. According to J. Viskovic (2023), cannabis is characterised by the potential of a sustainable and environmentally safe crop. E. Campiglia *et al.* (2020) evaluated the impact of various methods of growing hemp on the environment. The main factors of influence are the correct selection of varieties for cultivation, the density of sowing, and the timing of harvesting (Strzelczyk *et al.,* 2023). Results have been achieved in the case of biofertilisers and humic substances, but the decisive factor is the presence of moisture and high temperatures (Hammami *et al.,* 2022). However, cannabis can also have quite high productivity under water stress. From an economic standpoint, hemp is a crop that can produce yields on the so-called marginal lands (Blandinières *et al.,* 2022). This confirms the possibility of using hemp in organic farming.

The development of new varieties of crops requires clarification of ways to optimise their cultivation in order to realise their genetic potential. According to V.L. Dimitriev *et al.* (2021), increased yields and improved quality of hemp products are influenced by seeding rates. Thus, sowing hemp with a seed rate of 3.2 million pcs./ha, provides 3.32 t/ha of fibre (straw) with high quality indicators.

The paper by O. Horash *et al.* (2022) highlights the dependence of the yield of commercial seeds of hemp on the seeding rates and varietal characteristics. The maximum adaptive potential of the studied varieties USO 31, Hliana, and Hlesia (1,271, 1,506 and 1,737 t/ha, respectively) was noted for cultivation with a seeding rate of 0.6 million pcs./ha. The data obtained confirm the conclusions of other researchers regarding the dependence of hemp productivity on varietal characteristics. M. Baldini *et al.* (2020) determined that the yield of hemp seeds of the Bialobrzeskie variety is 0.61-0.65 t/ha and the Fedora variety – 0.92-1.0 t/ha. In the conditions of Serbia, M. Habán *et al.* (2022) found that the highest fibre yield was provided by the Bialobrzeskia variety (3.3±0.64 t/ha), and the highest seed yield was provided by the monoecious Novosadska variety (778.67±6.59 kg/ha). The productivity assessment (in terms of fibre and seeds) of six monoecious cannabis varieties was carried out in northern Greece (Tsaliki *et al.,* 2021). The highest fibre yield was observed in Futura 75 and Bialobrzeskie varieties (4.57 and 4.27 t/ha, respectively). Santhica 27, Tygra, and Bialobrzeskie varieties provided the highest seed yields – 2.7, 2.9, and 2.6 t/ha, respectively. The Bialobrzeskie variety under study recorded high fibre and seed yields.

The obtained experimental data are consistent with the conclusions of other researchers regarding the choice of hemp varieties depending on the area of use (for fibre or seeds). The fibre yield formation model is similar to the seed yield formation model (Baldini *et al.,* 2020), which is also confirmed in the presented studies and is important for the use of dual-use varieties. Such varieties have advantages over fibre-only varieties in terms of potential gross profit per hectare (Das *et al.,* 2020). It is important to select varieties for cultivation that may differ in the efficiency of water consumption in dry and hot conditions (Herppich *et al.,* 2020). This feature must be considered for the placement of agrocenoses in the conditions of unstable moisture, in which the experiments were conducted. According to M. Habán *et al.* (2022), the interaction of two factors, environmental conditions and genotype, plays a significant role in hemp production. The scope of use of hemp is constantly expanding, and accordingly, the territorial zone of cultivation of this crop is becoming wider. Now it is important to use cannabis not only for fibre, but also for seeds.

The increase in crop productivity under the influence of the use of microbiological preparations to activate the microbiological activity of the soil is widely covered in studies (Vlasyuk &Tymoshchuk, 2018; Panfilova, 2021). Y. Ulko (2019) highlights the increasing economic and environmental impact of the use of biologics in the cultivation of agricultural crops in organic farming. The high efficiency of using biodestructors for accelerated decomposition of plant residues is highlighted by Ye. Yurkevich and N. Valentiuk (2021).

Studies have confirmed that the cultivation of such agricultural crops as hemp using organic technologies has a positive effect on its productivity. The results of the analysis of scientific publications and trends in the development of hemp production indicate a lack of scientific developments on this topic, which increases the need for further research.

CONCLUSIONS

The most important factor for the effective cultivation of hemp using organic technologies are varietal characteristics. As a result of the assessment of five varieties of hemp, it was found that the yield of straw on average over the years of research ranged from 1.75-3.6 t/ha. The highest yield of hemp fibre was recorded in the Lara variety, and the lowest – in the Hliana variety. The fibre yield of hemp varieties depended on years of research. The most favourable year for the formation of crop productivity was 2021, and the least – 2020. The yield of straw and hemp fibres of the varieties under study was 4.09-5.33 and 1.74-3.58 t/ha, respectively, depending on the cultivation technology. It is confirmed that the cultivation of hemp using organic technologies does not cause a significant decrease in the yield of straw and fibres. There is an average direct correlation between the yield of straw and fibre (r=0.56), which indicates the influence of the variety and cultivation technology on this indicator. The use of a biodestructor contributed to an increase in the fibre yield of Hliana (3.5%) and Hloba (10.9%) varieties compared to the control. The yield of straw does not significantly

depend on the conditions of the year, in contrast to the yield of fibre (47%). However, it strongly depends on the variety (96%). The influence of cultivation technology and the interaction of factors does not exceed 4%. The influence of the variety on the formation of fibre yield was 48%. Organic technologies for growing Lara varieties ensure the formation of straw yields at the level of 4.96 and 5.0 t/ha, which does not significantly differ from the control.

The highest yield of hemp seeds on average for 2019-2020 was observed in the Sula variety (0.69 t/ha), which is 0.4-0.6 t/ha more compared to the standard. The average yield of seeds of the Zolotoniski 15, Lara, and Hloba varieties was 0.56-0.6 t/ha. Varietal characteristics showed the maximum impact on the yield of hemp seeds (66%). The yield of Lara seeds for organic cultivation did not significantly deviate from the conventional technology. Based on the conducted studies, it was found that Hloba, Zolotoniski 15, Lara, and Sula varieties are suitable for double cultivation for seeds and fibre. It is advisable to use the Hliana variety only for growing fibre. Further research may focus on studying the physical parameters of fibre and seed quality using organic cultivation technologies.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTERESTS

None.

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Особливості формування продуктивності сучасних сортів конопель посівних за органічної технології вирощування

Андрій Васильович Пилипченко
Аспірант
Полтавський державний аграрний університет
36003, вул. Сковороди, 1/3, м. Полтава, Україна
https://orcid.org/0000-0003-2044-8948

Микола Миколайович Маренич
Доктор сільськогосподарських наук, професор
Полтавський державний аграрний університет
36003, вул. Сковороди, 1/3, м. Полтава, Україна
https://orcid.org/0000-0002-8903-3807

Володимир Васильович Гангур
Доктор сільськогосподарських наук, старший науковий співробітник
Полтавський державний аграрний університет
36003, вул. Сковороди, 1/3, м. Полтава, Україна
https://orcid.org/0000-0002-5619-492X

Тетяна Миколаївна Тимощук
Кандидат сільськогосподарських наук, доцент
Поліський національний університет
10008, бульвар Старий, 7, м. Житомир, Україна
https://orcid.org/0000-0001-8980-7334

Леся Вікторівна Малинка
Кандидат сільськогосподарських наук
Науково-методичний центр вищої та фахової передвищої освіти
03158, вул. Смілянська, 11, м. Київ, Україна
https://orcid.org/0000-0001-8307-6681

Анотація. Коноплі посівні можуть використовуватися для отримання продукції і відтворення родючості ґрунтів. Адаптивний потенціал сортів конопель можна реалізувати завдяки оптимізації технологій їх вирощування. Метою досліджень було обґрунтування особливостей формування продуктивності сортів конопель посівних адаптованих до органічних технологій вирощування. Польові дослідження проведені протягом 2019-2021 рр. на вилужених чорноземах. Методи досліджень: польовий, лабораторний, статистичний і порівняльно-розрахунковий. Досліджено закономірності формування врожайності трести, волокна і насіння конопель посівних залежно від генетичного потенціалу сортів і технології вирощування. Оцінено придатність п'яти сортів конопель посівних для органічного вирощування. Встановлено, що впровадження органічної технології вирощування позитивно впливає на продуктивність культури. За органічного вирощування сортів Гляна і Глоба підвищення урожайності трести (0,07-0,11 т/га) було статистично неістотним порівняно з неорганічною технологією. Вирощування сортів Золотоніські 15 і Сула за органічних технологій збільшує на 0,14 т/га урожайність трести. У сорту Лара відмічено несуттєве зниження врожайності трести. Це підтверджує версію, що впровадження органічного вирощування конопель посівних не призведе до зниження рівня врожайності. Органічні технології вирощування конопель посівних сприяли підвищенню їх урожайності порівняно із класичними за умови правильного підбору сортів. Найкращу придатність для органічного вирощування за урожайністю волокна зафіксовано у сорту Лара. Отримані результати досліджень будуть використані для удосконалення і впровадження органічних технологій вирощування адаптованих сортів конопель посівних залежно від призначення на волокно чи насіння

Ключові слова: насіння; треста; волокно; генетичний потенціал; біодеструктор; кореляція

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 26(7), 66-78

UDC 633.1
DOI: 10.48077/scihor7.2023.66

Creation of source material by attracting different varieties of common winter wheat in breeding for adaptability, productivity, and grain quality

Valentyn Moskalets*
Doctor of Agricultural Sciences, Senior Research Fellow
Institute of Horticulture of the National Academy of Agrarian Sciences of Ukraine
03027, 23 Sadova Str., Novosilky vil., Ukraine
https://orcid.org/0000-0002-0831-056X
Svitlana Kotsyuba
PhD in Agricultural Sciences, Associate Professor
Uman National University of Horticulture
21100, 1 Instytutska Str., Uman, Ukraine
https://orcid.org/0009-0000-0949-376X
Zhanna Novak
PhD in Agricultural Sciences, Associate Professor
Uman National University of Horticulture
21100, 1 Instytutska Str., Uman, Ukraine
https://orcid.org/0009-0005-5046-9370
Vitalii Kryzhanivskiy
PhD in Agricultural Sciences, Associate Professor
Uman National University of Horticulture
21100, 1 Instytutska Str., Uman, Ukraine
https://orcid.org/0000-0001-9803-6893
Olga Yaremenko
PhD in Geological Sciences
Polissia National University
10002, 7 Staryi Blvd., Zhytomyr, Ukraine
https://orcid.org/0000-0002-2882-4621

Article's History:
Received: 19.04.2023
Revised: 24.06.2023
Accepted: 15.07.2023

Abstract. The relevance of the subject matter lies in the constant pursuit to improve and improve varieties of common winter wheat by using various genetic resources and breeding methods to achieve better adaptability, higher productivity, and superior grain quality. The purpose of the study was to expand the genetic diversity of common winter wheat, which combines high productivity and adaptability for further breeding in the context of food security. The research uses generally accepted methods and their modifications, which ensured high objectivity of the results obtained. Phenology,

Suggested Citation:
Moskalets, V., Kotsyuba, S., Novak, Zn., Kryzhanivskiy, V., & Yaremenko, O. (2023). Creation of source material by attracting different varieties of common winter wheat in breeding for adaptability, productivity, and grain quality. *Scientific Horizons*, 26(7), 66-78. doi: 10.48077/scihor7.2023.66.

*Corresponding author

morphological studies, and evaluation of breeding material based on economically valuable characteristics were carried out according to the methodology for conducting an expert examination of plant varieties. It was found that the involvement of the Ferrugineum 1239 sample before crossing allows forming a hybrid material with increased resistance against adverse abiotic environmental factors, which was observed on crops of breeding numbers 0284/18/1, 0135/18, 0209/18/1, etc. It was proved that consideration of the nature of inheritance and preservation of features of ear productivity elements at the level of the best parent components in combination with high quantitative features of the number of grains from the main ear, the weight of grains from the main ear, the weight of 1,000 grains in hybrid populations of the first generation, the above combinations of crosses *Triticum aestivum* var. *erythrospermum* with *Triticum aestivum* var. *barbarossa*, *Triticum aestivum* var. *erythrospermum* with *Triticum aestivum* var. *ferrugineum* can be valuable in the selection of common winter wheat. The practical value of the study lies in the fact that the findings expand information about the use of erythrospermum and lutescens and other varieties of common wheat in breeding for the productivity and quality of common winter wheat: *Triticum aestivum* var. *barbarossa* and *Triticum aestivum* var. *ferrugineum*. As a result of the research, the best samples (F_4) were transferred to the Nosivka Breeding and Research Station for further breeding work

Keywords: common winter wheat; varieties; *erithrospermum* Körn.; *lutescens* Alef.; *ferrugineum* Alef.; *barbarossa* Alef.; selection; new hybrid forms; evaluation

INTRODUCTION

Research and development of new varieties of common winter wheat with high adaptability to changing climatic conditions, high productivity, and superior grain quality is an extremely urgent task to ensure a stable harvest, increase productivity, and meet the needs of the population in food resources. The study of common wheat obliges producers to grow varieties that meet modern requirements – characterised by high environmental stability, productivity, and grain quality (Filip *et al.*, 2023). In turn, such issues require the breeder to work hard and responsibly to form the appropriate source material for further breeding (Suchowilska *et al.*, 2020). According to Kumar *et al.* (2022), climate change leads to a loss of biodiversity, and therefore, overexploitation and selection by individual traits have led to a decrease in the genetic diversity of common wheat. However, most breeders are aware of possible problems and work to create varieties (lines) of common wheat that are resistant to climate and adverse biotic environmental factors, using the types and diversity of wheat endowed with a complex of important genes (Pour-Aboughadareh *et al.*, 2021).

Varieties of common wheat have a number of genetic characteristics, which gives, first of all, geneticists and breeders valuable information for forming the source material and building a variety model. Chinese researchers Yang *et al.* (2023) suggest that the morphological features and physiological features of common wheat varieties have been honed over time, in particular, about 5.5 million years ago as a result of spontaneous crossing of two wild cereals – *Triticum urartu* Tumanian ex Gandilyan (2n=14) and *Aegilops* (not yet identified, but close to *Aegilops speltoides*, 2n=14), which separated from a common ancestor about 7 million years ago, formed the wild spelt, or wild emmer (*Triticum dicoccoides* (Körn. ex Asch. & Graebner) Schweinf., 2n=28), as the closest but not a direct carrier of subgenome B. Other researchers (Dvorak *et al.*, 2012) add that less than 1 million years ago wild spelt (*Triticum dicoccoides* gave rise to fertile tetraploid wheat *Triticum turgidum* (2n=28), that is, an allotetraploid in the nucleus of which the A and B genomes function.

According to Laugherotte *et al.* (2022), approximately 8-10 thousand years ago as a result of natural hybridisation of *Triticum turgidum* with *Aegilops tauschii* (DD, 2n=14) common allohexaploid wheat was formed (*Triticum aestivum* L., 2n=42), which gave rise to the emergence of modern genotypes. Therefore, common wheat, which has 42 chromosomes and about 17 billion base pairs, is the result of a combination of three diploid genomes – AABBDD and consists of 90-96 thousand genes evenly distributed over 6 sets of chromosomes of genomes A, B, and D, where the A – haploid genome close to *Triticum urartu*, B – haploid genome *Aegilops*, close to *Aegilops speltoides*, and the D – haploid genome of a species close to *Aegilops tauschii*, in this case, the latter is the result of hybridisation between *Triticum urartu* and *Aegilops speltoides* (Haider, 2013).

According to the paper (Mirzaghaderi & Mason, 2019), the D genome of allohexaploid common wheat is the least diverse of the three wheat genomes and is undoubtedly less diverse than that of the diploid progenitor genome *Aegilops tauschii* (2n=DD), which is important when selecting varieties of common wheat as a starting material. According to Li *et al.* (2022), the donor subgenome in common wheat is a separate and most likely extinct diploid species that has separated from the carrier ancestor of the B genome, to which the existing species *Aegilops speltoides* belongs. Modern research indicates the importance of *Aegilops* muticum as a donor of common wheat subgenomes B and D (Avni *et al.*, 2021; Li *et al.*, 2022). Therefore, the process of introgression – from wild emmer wheat to domesticated emmer wheat or bread wheat – has become an

important mechanism in increasing genetic diversity during the evolution of common wheat (Zhou *et al.*, 2020). In this regard, a wide variety of common wheat biotypes has been created since the domestication of wheat by unconscious selection based on adaptive characteristics, and over time – by empirical selection, which is characterised by a unique biopotential both in terms of grain yield and quality, and tolerance to adverse biotic and abiotic environmental stresses (He *et al.*, 2019).

However, the biological potential of common wheat varieties is not fully used in breeding, in particular, during the period of global climate change. For example, in Ukraine's grain sector, common winter wheat is sown on an area of 6-8 million hectares, summer wheat – 160-400 thousand hectares, represented by a number of varieties (in particular, as of 2023, more than 721 varieties of common wheat are registered in the State register of plant varieties (State register of plant varieties, 2023), of which only awned (*erythrospermum*) and awnless (*lutescens*) varieties dominate. It remains relevant to introduce new genes into modern wheat varieties to reduce the negative impact of pathogens, and according to Singh *et al.* (2022), among 200 of which, 50 cause significant economic damage (about 20% of wheat crops are lost annually).

The purpose of the study was to develop new genotypes of common winter wheat, combining high adaptability, productivity, and grain quality for further breeding in the context of food security.

MATERIALS AND METHODS

The study was conducted during 2016-2021 at the Nosivka Breeding and Research Station of the V.M. Remeslo Myronivka Institute of Wheat the National Academy of Agrarian Sciences of Ukraine (NAAS of Ukraine) (southern part of Polissia of Ukraine) and the Institute of Horticulture of the NAAS of Ukraine (Northern Forest-Steppe of Ukraine). Based on the designed model of the variety, a programme was developed in which the ways of breeding new raw material of common wheat were consistently substantiated. In 2016-2017, breeding work began with a nursery of source material, which consisted of a collection nursery represented by varieties from different countries of the world, which are sources and donors of economically valuable traits and biological properties. The total set of source materials was formed at the expense of the author's own line database and samples provided by the National Centre for Plant Genetic Resources of Ukraine of the V.Y. Yuriev Institute of Plant Production of NAAS of Ukraine. Agricultural techniques for growing winter wheat are generally accepted for the Polissia and Forest-Steppe zones of Ukraine. Seeds intended for sowing in nurseries of the source material were placed in parchment bags, on which the plot number, the number or mass of grains, and the name of the nursery were indicated. Sowing of the source material (collections, hybrids of different generations) was carried out manually. During 2018-2022, the hybrid nursery included first- to fourth-generation (F_{1-4}). Hybrid seeds were sown separately, one ear – on one or two rows, the number of which depended on the number of selected ears from each combination, the number of parent forms and standard plots. The collection of common winter wheat source material was evaluated for productivity, lodging resistance, and disease resistance for further creation of new forms with a complex of valuable economic characteristics according to the methods of plant variety expertise (Tkachyk *et al.*, 2016).

The best varieties (lines) of common winter wheat for crossing were sown manually in autumn with an area of 2 m^2 each, with a row spacing of up to 20 cm. Selection of parent pairs for paired (simple) crosses and hybridisation was carried out in 2018 (Table 1, Fig. 1).

Table 1. *Parent forms of common winter wheat of species erythrospermum (Erithrospermum Körn.) and lutescens (Lutescens Al.) used in crossing with common wheat varieties barbarossa (Barbarossa Al.) and ferrugineum (Ferrugineum Al.)*

No.	Name of parent forms	Origin
1.	PKB Rodika	Romania
2.	L59-95 (UA0108016)*	Donska n/k × [(Maris Madler × Pony) × Donska n/k]
3.	Kyivopolka (UA0123746)	(Chisinau intensive × (Polisska 87 × Kiyanka)
4.	Svyatdonivka (UA0123749)	00239 × Donska n/k

Note:* *– number in the national catalogue assigned by the National Centre for Plant Genetic Resources of Ukraine*
Source: *developed by the authors*

Figure 1. *Parent components (varieties, lines) involved in hybridisation: 1. Triticum aestivum L. var. ferrugineum (Ferrugineum 1239); 2. Triticum aestivum L. var. barbarossa; 3. Kyivopolka*; 4. PKB Rodika**; 5. L 59-95; 6. Svyatdonivka*; 7. Priaspa**; 8. KS 14***

Note: ** species erithrospermum; ** species lutescens*

Source: *photographed by the authors*

The main method that was used to increase hereditary variability in populations is hybridisation. Crossing was carried out according to the scheme: simple paired. Crossing was carried out by pollination of neutered TVEL spikelets by the Norman Borlaug Global Rust Initiative (2020). Phenological observations were carried out mainly for the following phases of plant development: germination, tillering, earing, maturation (waxy, full ripeness). Field germination and plant survival were determined. Resistance to lodging was evaluated on a 5-point scale according to the method of examination of plant varieties (Tkachuk *et al.*, 2016).

The mass of seeds for sowing was considered in the section of plots and repetitions. Hybrid populations F_2 (grain F_3), which received a positive rating in F_1, were sown in two ecological points (southern part of Polissia and the Northern Forest-Steppe) to make better use of the spectrum of genetic variation for the selection of elite plants of the corresponding agroecotypes. Generation F_1-F_4 sown in a hybrid nursery, and next to F_1-F_2, parental forms were sown manually along the edges – after 20-30 numbers. Working with split generations consisted of selecting biotypes that correspond to the purpose of the work. The protein and gluten content were determined by infrared spectrometry (Chen *et al.*, 2017). Harvesting was carried out manually during the full ripeness phase.

The degree of dominance was calculated by the equation:

$$hp = \frac{F1-Mp}{Pmax-Mp}$$

where: *hp* – degree of dominance; *F*1 – indicator of the trait of a particular hybrid; *Mp* – average value of parent forms; Pmax – maximum value of one of the parent components.

The data was grouped according to classification by G.M. Beil, R.E. Atkins (according to Zymogliad *et al.,* 2021): partial negative dominance -1⩽hp<-0.5, partial positive dominance +0.5<hp ⩽+1, positive over-dominance hp>+1, intermediate inheritance -0.5⩽hp⩽0.5, negative over-dominance (depression) hp<-1. The reliability of the difference between the average values of indicators in parent forms and hybrids of the first generation was determined using variance analysis. The degree of excess of the trait level in first-generation hybrids over their parents was determined by true heterosis *H˙bt*, which allows identifying the highest level of manifestation of the trait of first-generation hybrids in comparison with the best parent form and assessing the breeding value and probability of forming transgressive forms in a hybrid combination.

When determining the true heterosis, the equaiton was used:

$$Hbt = \frac{\dot{F1-BP}}{BP} \text{ x } 100\ (\%)$$

where Hbt – true heterosis; F1 – value of the trait in the first-generation hybrid; BP – value of the trait in the best of the parent components.

Significant values were values that exceeded the indicators of the best parent component by more than 5%. Trait inheritance Rate (N^2) was determined by variations of parent components and hybrids:

$$\dot{H^2} = \frac{\sigma_G^2}{\sigma_P^2},$$

where σ_G^2 – variation genetic; σ_P^2 – variations of parent components.

Inheritance rate (h^2) was determined using regression coefficients between the values of traits of parent components and hybrid generations by the equaiton:

$$h^2 = b_{БГ},$$

where h^2 – inheritance rate in a narrow sense; $b_{БГ}$ – regression coefficient between the trait in parent components and hybrids.

The dependence of indicators in hybrids on the average value of indicators of traits in parent components was determined by the equaiton:

$$y = f(x) + \varepsilon$$

where y – amount of change in the indicator; $f(x)$ – current factor; ε – random error describing the effect of factors not considered in the experiment. The regression coefficient was considered the average inheritance coefficient.

The reliability of the results was evaluated using the MS Excel programme.

RESULTS

As noted by Moskalets *et al.* (2020; 2022) the breeding process can be divided into three consecutive stages: development of a model of the future variety and determination of ways to implement it; selection of initial forms and creation of synthetic material for selection; development of the variety as a stable biological system.

In the process of crossing hexaploid wheat of the common variety erythrospermum (*Triticum aestivum* var. *erythrospermum Körn.*) with common wheat varieties barbarossa (*Triticum aestivum* L. var. *barbarossa* (Alef.) Mansf.) and ferrugineum (*Triticum aestivum* L. var. *ferrugineum* Al.), which also belongs to the group of hexaploid wheat (2n=42), fertile hybrids are formed. Crossing increases the number of genetic recombinations. For first-generation hybrids (F_1) grain binding is noted, that is, there is a normal course of chromosome conjugation in meiosis, and viable gametes are formed, the fusion of which gives a viable grain.

Hexaploid variety of common wheat *Triticum aestivum* L. var. *barbarossa* (Alef.) Mansf. is known as a source of signs of grain quality. First generation hybrids (F_1) *Triticum aestivum* var. *erythrospermum* Körn. × *Triticum aestivum* L. var. *barbarossa* (Alef.) Mansf. were mostly low-growing – up to 105 cm tall, while they were marked by a strong stem, a spinous red spike with tomentous spikelet scales and an oval or egg-shaped red powdery grain. In F_2-F_3 for generations, plants that were similar in phenotype were isolated with different frequency *Triticum aestivum* var. *erythrospermum* Körn., but combined the signs *Triticum aestivum* L. var. *barbarossa* (Alef.) Mansf. (Fig. 2).

1 2 3

Figure 2. *Main ear of the best breeding numbers F_4: 1. 0135/18 (Kyivopolka × Triticum aestivum L. var. ferrugineum (Alef.) Velican.; 2. 0284/18 (analogue × Triticum aestivum L. var. ferrugineum (Alef.) Velican.; 3. 0133/18/3 (Kyivopolka × Triticum aestivum L. var. barbarossa (Alef.) Mansf.)*

Source: *photographed by the authors*

First generation hybrids (F_1) *Triticum aestivum* var. *erythrospermum* Körn. × *Triticum aestivum* L. var. *ferrugineum* Alef. were characterised as medium-sized – 105-120 cm and prone to lodging, with long (>25 cm), narrow (<1 cm) green leaves, spinous and red-yellow with a bronze sheen ear at full ripeness and red grain. Hybrids of the first generation of combinations of both erythrospermum × barbarossa and erythrospermum × ferrugineum were characterised by a low grain weight from the ear (<1.5 g) and a weight of 1,000 grains (<40 g), compared with the parent forms of the erythrospermum variety, which had indicators of more than 2 g and 50 g, respectively. In the second and third generations, plants with a higher grain weight from the main ear were selected, which exceeded the parent forms of barbarossa and ferrugineum, and amounted to more than 2 g. The minimum value of the inheritance coefficient used for successful selection in generations F2-3 was 0.50. For hybrids of combinations of Kyivopolka × *Triticum aestivum* L. var. *barbarossa* and *Triticum aestivum* L. var. *barbarossa* × PKB Rodika, the ratio of length inheritance coefficients was 0.81/0.71 and 0.55/0.46, respectively, the difference between which is insignificant, this indicates that the genotypic variability in these hybrids is due to additive effects of genes, and the selection by phenotype is close to the selection of the corresponding forms (Table 2).

***Table 2**. Morphological features and indicators of productivity elements of parent forms and hybrids (F_3)*

Selection number	Name of the parent forms involved in crossing	Plant height, cm	Colour of the ear	Presence of awns/ tomentum of spikelet scales	Ear length, cm	Number of grains from the main ear, pcs.	Weight of grains from the main ear, pcs.	Weight of 1,000 grains, g
342/16	*Triticum aestivum* L.var. *ferrugineum*	101.5	light brown	yes/no	8.7	38.2	1.85	40.4
368/16	*Triticum aestivum* L. var. *barbarossa*	98.7	brown	yes/yes	9.5	41.5	1.92	45.3
103/18	L59-95**	85.8	straw yellow	yes/no	8.3	45.6	2.11	50.5
166/17	PKB Rodika*	92.5	white	no/no	10.5	49.5	2.20	48.6
159/16	Kyivopolka**	87.5	white	yes/no	10.7	52	1.95	51.3
158/16	Svyatdonivka**	79.5	white	yes/no	9.5	59	2.72	52.5
101/16	Analog**	88.3	straw yellow	yes/no	9.1	48.7	2.03	46.7
0208/18/2	*Triticum aestivum* L. var. *barbarossa* × PKB Rodika	121.5	brown	no/yes	11.2	54.5	2.36	47.2
0208/18/3	*Triticum aestivum* L. var. *barbarossa* × PKB Rodika	96.5	white	no/no	11.5	44.6	2.17	50.4
0207/18/1	*Triticum aestivum* L. var. *barbarossa* × Svyatdonivka	98.3	white	yes/yes	11.0	57	2.63	48.5
0209/18/1	*Triticum aestivum* L. var. *barbarossa* × *Triticum aestivum* L. var. *ferrugineum*	75.5	brown	yes/yes	8.5	48	2.42	48.4
0209/18/3	*Triticum aestivum* L. var. *barbarossa* × *Triticum aestivum* L. var. *ferrugineum*	103.6	brown	yes/yes	9.9	59	2.81	49.2
0212/18/1	*Triticum aestivum* L. var. *barbarossa* ×*Triticum aestivum* L. var. *ferrugineum*	91.4	brown	yes/yes	8.9	40	1.98	49
0212/18/2	*Triticum aestivum* L. var. *barbarossa* × *Triticum aestivum* L. var. *ferrugineum*	110.5	brown	yes/no	10.2	53	2.68	51.2
0137/18/1	L 59-95 × *Triticum aestivum* L. var. *barbarossa*	83.5	red-brown	yes/no	10.7	81	4.14	51.6
0133/18/1	Kyivopolka × *Triticum aestivum* L. var. *barbarossa*	107.5	brown-yellow	yes/no	11.3	56	2.7	50.2
0133/18/3	Kyivopolka × *Triticum aestivum* L. var. *barbarossa*	93.4	light brown	yes/no	10.1	74	3.82	53.2
0135/18	Kyivopolka × *Triticum aetsivum* L. var. *ferrugineum*	87.8	light brown	yes/no	11.2	44	2.24	52.8
0284/18/1	Analog** × *Triticum aestivum* L. var. *ferrugineum*	90.5	brown	yes/no	9.7	65	3.2	52.2

***Note:** *species lutescens; **species erythrospermum*
***Source:** compiled by the authors*

When analysing the yield structure of hybrids in the first generation, the number and weight of grains in the main ear exceeded the parent components in most of the combinations under study. In combination L 59-95 × *Triticum aestivum* L. var. *barbarossa*, it was noted that the degree of phenotypic dominance (hp) in the inheritance of the trait the number of grains in the ear in the hybrid material was 16.0%, and the trait – the mass of grains from the ear – 21.3, which indicates a positive over-dominance. This fact is evidenced by indicators of the degree of phenotypic dominance and other combinations of Kievopolka × *Triticum aestivum* L. var. *barbarossa* – 4.4 and 94.5%, Analog × *Triticum aestivum* L. var. *ferrugineum* – 4.4 and 14.0%, respectively. According to the economically valuable trait, the weight of 1,000 seeds of the above-mentioned hybrids of the first generation significantly exceeded the parent components.

As a result of hybridological analysis of hybrids of the first generation when crossing samples *Triticum aestivum* L. var. *barbarossa* with semi-dwarf lines and varieties of common wheat of the erythrospermum

variety, inheritance of traits of the number and weight of grain from the ear, the weight of 1,000 grains, and the length of the ear according to the type of positive super-dominance was noted. The inheritance of the number of grains in the main spikelet trait by the type of positive super-dominance was observed in many hybrids of the studied combinations. It was found that almost all samples overwintered well during 2018-2022 and were assigned to the first group, in which the condition of the ground part was only up to 20-25% damaged, and the winter hardiness score was not lower than 8 (Table 3).

***Table 3**. Ripeness group and indicators of resistance to adverse environmental factors of hybrids (F_3) compared to parent forms*

Selection number	Name of the parent forms involved in crossing	Ripeness group	Winter hardiness	Drought resistance	Resistance to shedding	Resistance to lodging
			score			
342/16	*Triticum aestivum* L. var. *ferrugineum*	mr*	9.0	9.0	8.7	7.0
368/16	*Triticum aestivum* L. var. *barbarossa*	mr	7.2	9.0	8.0	8.0
103/18	L59-95	me	8.5	8.5	9.0	8.7
166/17	PKB Rodika	mr	8.0	7.0	8.5	8.0
159/16	Kyivopolka	me	8.6	8.5	8.3	9.0
158/16	Svyatdonivka	mr	9.0	9.0	8.5	8.0
101/16	Analog	er	8.6	8.2	8.2	8.7
0208/18/2	*Triticum aestivum* L. var. *barbarossa* × PKB Rodika	mr	8.2	8.0	8.5	8.5
0208/18/3	*Triticum aestivum* L. var. *barbarossa* × PKB Rodika	mr	7.5	7.0	9.0	8.7
0207/18/1	*Triticum aestivum* L. var. *barbarossa* × Svyatdonovka	mr	8.7	8.5	8.5	8.0
0209/18/1	*Triticum aestivum* L. var. *barbarossa* × *Triticum aestivum* L. var. *ferrugineum*	mr	9.0	9.0	8.5	8.0
0209/18/3	*Triticum aestivum* L. var. *barbarossa* × *Triticum aestivum* L. var. *ferrugineum*	ml	9.0	9.0	8.5	7.2
0212/18/1	*Triticum aestivum* L. var. *barbarossa* × *Triticum aestivum* L. var. *ferrugineum*	mr	8.5	8.7	8.2	8.5
0212/18/2	*Triticum aestivum* L. var. *barbarossa* × *Triticum aestivum* L. var. *ferrugineum*	mr	8.0	8.5	8.8	7.7
0137/18/1	L 59-95 × *Triticum aestivum* L. var. *barbarossa*	me	8.5	9.0	8.5	7.5
0133/18/1	Kyivopolka × *Triticum aestivum* L. var. *barbarossa*	mr	8.5	9.0	8.0	7.5
0133/18/3	Kyivopolka × *Triticum aestivum* L. var. *barbarossa*	mr	8.5	8.5	8.3	8.0
0135/18	Kyivopolka × *Triticum aestivum* L. var. *ferrugineum*	mr	9.0	9.0	8.0	8.5
0284/18/1	Analog** × *Triticum aestivum* L. var. *ferrugineum*	er	9.0	9.0	8.5	8.5

***Note:** ml – middle-late; mr – middle-ripened; me – middle-early; er – early-ripened*
***Source:** compiled by the authors*

Breeding numbers 368/16 and 0208/18/3 were assigned to the second wintering group, as their leaf surface was damaged by more than 25%. But it is worth noting that sample 368/16 or *Triticum aestivum* L. var. *barbarossa* during April-June, was characterised as highly drought-resistant (9 points), which was also noted in hybrid plants of breeding numbers 0209/18/1, 0209/18/3, 0133/18/1 and 0137/18/1, which were created using the above number.

The Ferrugineum 1239 sample was characterised by high winter and drought resistance (9 points). The involvement of this sample in crossing significantly resulted in an increase in resistance against adverse abiotic environmental factors, which was observed on crops

of breeding numbers 0284/18/1, 0135/18, 0209/18/1, etc. However, the Ferrugineum 1239 sample of common wheat of the ferruginem species showed an increased tendency to lodging. During 2018-2022, the average score of the sample's resistance to lodging was 7.0 points, which is lower compared to *Triticum aestivum* L. var. *barbarossa* and hybrids that are being created *Triticum aestivum* L. var. *ferrugineum* (Ferrugineum 1239) used.

The use in hybridisation of early-maturing common wheat varieties erythrospermum Analog and medium-early line L 59-95 with wheat varieties barbarossa and ferrugineum allowed obtaining, in comparison with the latter, earlier-maturing biotypes with high resistance to adverse abiotic environmental factors. These are the selection numbers 0284/18/1 (Analog × *Triticum aestivum* L. var. *ferrugineum*), 0137/18/1 (L 59-95 × *Triticum aestivum* L. var. *barbarossa*). In general, it is worth noting that the breeding numbers of new hybrids were characterised as resistant to shedding.

According to the State Standard of Ukraine DSTU 3768:2010 (2010), common wheat is classified into 4 classes, which are regulated by quality indicators, in particular, wheat of Class 1-3 is used in the domestic market for food needs (bakery and flour industry) and exports, and wheat of Class 4 – for food and non-food needs. According to Table 4, it can be seen that almost all samples – both source material and hybrids – belong to Class 1 of wheat quality in terms of the mass fraction of protein, in terms of dry matter, and the mass fraction of raw gluten.

***Table 4**. Grain quality indicators of hybrids (F_3) compared to parent forms*

Selection number	Name of the parent forms involved in crossing	Mass fraction of protein, in terms of dry matter, %	Mass fraction of raw gluten, %
342/16	*Triticum aestivum* L. var. *ferrugineum*	14.7	29.5
368/16	*Triticum aestivum* L. var. *barbarossa*	16.5	31.3
103/18	L59-95	14.5	28.5
166/17	PKB Rodika	14.0	29.5
159/16	Kyivopolka	13.6	29.0
158/16	Svyatdonivka	13.5	28.2
101/16	Analog	14.8	30.5
0208/18/2	*Triticum aestivum* L. var. *barbarossa* × PKB Rodika	14.2	29.7
0208/18/3	*Triticum aestivum* L. var. *barbarossa* × PKB Rodika	16.4	31.8
0207/18/1	*Triticum aestivum* L. var. *barbarossa* × Svyatdonivka	14.7	30.7
0209/18/1	*Triticum aestivum* L. var. *barbarossa* ×*Triticum aestivum* L. var. *ferrugineum*	15.0	32.5
0209/18/3	*Triticum aestivum* L. var. *barbarossa* × *Triticum aestivum* L. var. *ferrugineum*	13.5	28.4
0212/18/1	*Triticum aestivum* L. var. *barbarossa* × *Triticum aestivum* L. var. *ferrugineum*	14.2	28.8
0212/18/2	*Triticum aestivum* L. var. *barbarossa* × *Triticum aestivum* L. var. *ferrugineum*	16.0	31.7
0137/18/1	L 59-95 × *Triticum aestivum* L. var. *barbarossa*	16.1	32.5
0133/18/1	Kyivopolka × *Triticum aestivum* L. var. *barbarossa*	14.6	29.5
0133/18/3	Kyivopolka × *Triticum aestivum* L. var. *barbarossa*	16.8	32.5
0135/18	Kyivopolka × *Triticum aestivum* L. var. *ferrugineum*	14.0	27.5
0284/18/1	Analog** × *Triticum aestivum* L. var. *ferrugineum*	14.0	28.5

***Source:** compiled by the authors*

It was found that the grain of common wheat of the barbarossa variety is characterised by a high content of protein and gluten. The involvement of the above-mentioned wheat in hybridisation improved the grain quality of the hybrid material, in particular, samples with a protein content of at least 16% and raw gluten content of at least 30% were selected based on the selection results. These include the selection numbers 0208/18/3, 0212/18/20133/18/3, and 0137/18/1.

Based on the above results, there are objective possibilities when crossing different varieties of common wheat to create new forms with an increased potential for productivity and resistance to adverse environmental factors, since these properties are controlled by different genetic systems. The selected hybrids, which differ in the nature of the manifestation of traits and are characterised by a satisfactory combination of them with productivity, can be an excellent starting material

for further breeding of common wheat for adaptability and productivity.

DISCUSSION

The use of the lutescens varieties in breeding combination with others, in particular erythrospermum, allows forming a valuable source material in terms of adaptability and quality. In particular, researchers at the V.Y. Yuriev Institute of Plant Industry of NAAS of Ukraine (Leonov *et al.*, 2020) determined that the lutescens wheat species are carriers of Vrn genes, in particular, the lutescens 540 variety with one dominant Vrn-A1 gene, the lutescens 516 variety with the dominant Vrn-A1 allele and is polymorphic to the VrnB1 gene, and the above-mentioned varieties are characterised by an increased content of carotenoids in flour, which is important in breeding for quality. Moreover, considerable attention in breeding is attracted by wheat of the albidum species, since along with lutescens, it serves as a donor of awnless trait, and was also characterised by high grain quality. As a result of its use in hybridisation, early-maturing awned and awnless varieties were created with high grain quality and average indicators of dough and bread. Also of great importance in the selection of common wheat are the species gostianum and velutinum, based on which the varieties Koral Odeskii and Ulyanivka, respectively, are created. The varieties milturum and caesium are the most common among the varieties of spring development type. In particular, the latter variety is common in the countries of Transcaucasia. Varieties of nigriaristatum, erythroleucone, alborubrum, and grekum are not very common. However, the Azerbaijan Research Institute conducts serious breeding studies with the latter variety, in particular, the early-maturing white-grain variety Gobustan has been created, which is characterised by high drought resistance, yield, and grain quality (Hasanova *et al.*, 2019). Also in Azerbaijan, work is carried out with a ferrugineum variety. In particular, in the conditions of the unsecured boghara of Nagorny Shirvan (780-810 m above sea level, Kobustan Zonal Experimental Station, the above-mentioned research institute), not only *lutescens*, *erythrosperm* common wheat (*Triticum aestivum* L.) varieties are studied, but also biotypes of the variety *ferrugineum* in which, according to the results of research, winter and frost resistance is high – at the level of 8-9 points and, accordingly, high resistance to fungal diseases, including yellow rust is high in epiphytic years – about 68%.

Local samples of *Triticum aestivum* L. ps. *barbarossa*: Azgr-9558, Azgr-9556, Azgr-9555, etc., and *Triticum aestivum* L. var. *ferrugineum* (Alef.) Mansf.: Azgr-9539, Azgr-9538, etc., are registered at the Institute of Genetic Resources of the National Academy of Sciences of Azerbaijan, which are widely used in drought tolerance breeding (2020).

The Scientific Centre for Agrobiotechnology of Armenia preserves a number of samples of common wheat, which are represented by varieties *Triticum aestivum* L. var. *Ferrugineum* Alef. collected in the Syunik region and *Triticum aestivum* L. var. *lutescenc* Alef. selected in the Kotayk region of the above-mentioned country and is a valuable source material for breeding for adaptability to adverse abiotic environmental factors (Agrobiotechnology Scientific Center Branch, 2020).

The European search catalogue of plant genetic resources also reports that the Georgia Bank of Plant Genetic Resources has a sample of *Triticum aestivum* L. var. *ferrugineum* Alef., collected at an altitude of 552 m, which is stored at the I. Lomuri Institute of Agriculture and is in demand among geneticists and breeders (EURISCO, 2023). Also in the above-mentioned country, as one of the Centres of wheat origin and the birthplace of numerous wheat varieties, many of which are endemic, the winter wheat variety Tsiteli doli (*Triticum aestivum* var. *ferrugineum*) was created, which is adapted to the conditions of heavy poor soils, drought and frost-resistant, and highly resistant to diseases. Breeders take this variety as a standard for grain yield and quality. Although when it is grown on non-irrigated land (which is the norm), the yield is somewhat reduced and there is a tendency to lodging, but the taste and baking qualities are better than when grown in irrigated fields. Bread baked from this flour has a characteristic taste, bluish colour, and retains its freshness for up to a week. Today, Akhaltsihis Tsiteli doli is grown only in 25-30 farms in Georgia, which grow it for their own needs and for bakeries (Slow Food Foundation for Biodiversity, 2023). Another variety is Vardzia, which belongs to the species *Triticum aestivum* var. *ferrugineum* (Alef.) Velican, created by the Institute of Agriculture of Georgia, by the method of induced mutagenesis from the population variety Hulugo, by the effect of a 0.01% solution of the chemical mutagen NMM (nitrosomethylurea) on seeds. The above-mentioned variety is characterised by high drought resistance and resistance to fungal diseases and has been allowed to spread in all regions of Georgia with common wheat breeding and crop production (Natsarishvili *et al.*, 2016).

It is worth noting that the search for genetic diversity of ancient wheat varieties for breeding is also carried out in other countries, in particular in Turkey (regions of Central and Central-Eastern Anatolia and Cappadocia), the dominant local species of common wheat (87.5%) with a wide variety of morphotypes have been identified: albirubrum, albidum, erythroleucum, delfium, ferrugineum, and erythrospermum. Biotypes of the above-mentioned species are carefully preserved in farm fields in Turkey, Afghanistan, Iran, etc., as part of the CIMMYT project to preserve ancient wheat species, multilocal testing them, as valuable genetic resources for solving breeding and crop production problems (Morgounov *et al.*, 2016).

In 2010-2013, an inventory of ancient wheat varieties that are still grown by ancient farmers was

conducted on the territory of Uzbekistan, as a result of which it was found out that most of them belong to the species *ferrugineum*, *erythrospermum*, and *greacum*, it is important for the development of these varieties of source material to create varieties adapted to the conditions of the above-mentioned country (Baboev *et al.*, 2021). Similar studies were conducted by other researchers (Morgounov *et al.*, 2021) in many regions of Afghanistan, where the majority of local common wheat varieties were attributed to the species erythrospermum and greacum, accounting for more than 80%. And the territory of Kazakhstan, which is characterised by a variety of natural and climatic zones and extreme instability of meteorological conditions for years and seasons of the year, which requires the breeder to create genetically diverse varieties of winter wheat of the southern non-irrigated mountain agroecotype, represented by the following species: barbarossa, pyrotrix, lutescens, ferrugineum, erythrospermum, etc. It is worth noting that the involvement of biotypes of the barbarossa species in breeding allows obtaining varieties characterised by an average grain yield and winter hardiness, a high content of gluten (36.4 and 37.3%) and protein (15.8 and 18.2%), in particular, these are the well-known varieties Alatai and Karasai (Wheat of Kazakhstan, 2020).

In Ukraine, less attention is paid to the study of biotypes of the barbarossa and ferrugineum, in particular when using induced mutagenesis. In particular, at the Genetics, breeding and seed production of Bila Tserkva National Agrarian University from the seeds of mutant 42 (which was obtained by the action of DMS 0.025% concentration on seeds of the Ilyichivka variety) re-treated with ethylenimine 0.125% concentration, forms of dwarf (<65 cm) and semi-dwarf (>65-80 cm) types of development and varieties erythrospermum, suberitrospermum, and barbarossa were obtained, the latter biotypes were characterised by average productivity, inferior to the previous two (Khomenko & Fedorenko, 2011).

It is worth noting that the samples of *ferrugineum* are a standard of winter hardiness, such as the sample Ferrugineum 1239 (9 points) and resistance to the expression of hybrid necrosis and dwarfism and whitecap chlorosis genes in common varieties in Armenia (Alti-agach, Akhtamar, Armyanka, Karmir slfaat, Leninakan 3, Leninakan 216, etc.) (Sadoyan, 2017).

As noted by Yu. Kolupaev *et al.* (2023), over the past decades, Ukraine has experienced abnormally high air temperatures and droughts at different times of the year, including the autumn period, which leads to the establishment of stressful conditions for winter cereals, especially common wheat at the very beginning of ontogenesis. Therefore, selection to create sources and donors of valuable traits, including those that will determine the adaptability and quality of the new gene pool, will not lose its relevance.

Summarising the above, it can be stated that scientists are concerned about the impoverishment of the diversity of common wheat, so in many countries measures are being taken to create genetic banks to preserve biotypes belonging to varieties with valuable economic characteristics, in particular *erythrospermum, lutescens, ferrugineum, barbarossa,* etc., well-adapted to local conditions in order to attract them to the breeding process and obtain forms that are resistant to adverse environmental factors with high grain yield and quality.

CONCLUSIONS

A low level of variability in the main characteristics of productivity of the main ear (the length of the ear, the number of spikelets in the ear, the number of grains and the weight of grains from the ear) was established for crossing common wheat varieties erythrospermum with varieties barbarossa and ferrugineum, which indicates a high efficiency of selection for these characteristics.

It was found that when crossing common wheat varieties erythrospermum with common wheat varieties barbarossa and ferrugineum, the number of genetic recombinations increases, which, in turn, affects a significant number of forms with a complex of economically valuable traits. Hybrids of erythrospermum × barbarossa were characterised by the number of plants with a thickened stem, white and tomentous ear, red and not always naturist grain, medium ripeness, increased heat resistance, and hybrids of barbarossa × erythrospermum – vrown, mostly not tomentous ear, red and naturist grain, increased winter hardiness.

It was determined that hybrids of the ferrugineum × erythrospermum combinations were characterised by a tendency to lodging. In F_3, forms with a consistently high level of grain weight from the main ear and a weight of 1,000 grains are identified, compared to the mother form, which was common wheat of the variety *erythrospermum*. It is shown that the highest weight of 1,000 grains had hybrids selected from the population from crossing the variety erythrospermum (Kyivopolka, Analog) and ferrugineum, which was more than 50, with fluctuations in variability of about 4 g. This trend was also noted in hybrids of the combination of crossing another line of the erythrospermum variety with the line of the barbarosa variety, where the weight of 1,000 grains was also high and ranged from 48.6 to 49.5 g.

It was found that by the weight of grains from the main ear, the highest degree of heterosis (3.9-7.4%) was observed in combinations of L 59-95 × *Triticum aestivum* L. var. *barbarossa*, Kyivopolka × *Triticum aestivum* L. var. *barbarossa*, Analog × *Triticum aestivum* L. var. *ferrugineum*, *Triticum aestivum* L. var. *barbarossa* × *Triticum aestivum* L. var. *ferrugineum*. Studies of selected hybrids have shown that the weight of 1,000 grains for hybrids of erythrospermum × Barbarosa and erythrospermum × ferrugineum is the most stable feature, in contrast to the characteristics of the mass of grains and the number of grains from the main and side ears, the indicators of which vary to a much greater extent. It

was found that a number of breeding numbers of combinations of common wheat varieties erythrospermum with barbarossa determined high genotypic effects and stability of their manifestation in terms of grain quality indicators (protein content, gluten).

For further breeding to create new varieties, a hybrid material of common winter wheat of the erythrospermum variety was prepared with the participation of related varieties of winter wheat barbarossa and ferrugineum with red and amber grain in combination with high grain quality (protein and gluten content), resistance to lodging and fungal pathogens, and productivity of the main ear.

ACKNOWLEDGEMENTS

The authors would like to express their sincere gratitude to the employees of the National Centre for Plant Genetic Resources of Ukraine of the V.Y. Yuriev Institute of Plant Production of NAAS of Ukraine (Kharkiv), in particular, to Candidates of Biological Sciences Viktor Kuzmovych Ryabchun and Roman Lvovych Bohuslavskyi for providing wheat samples and a researcher at the Nosivka Breeding and Research Station of the V.M. Remeslo Myronivskyi Wheat Institute of NAAS of Ukraine (Doslidne, Chernihiv Oblast) Vitalii Ivanovych Moskalets and Chief Researcher of the Institute of Horticulture of NAAS of Ukraine, Doctor of Biological Sciences, Professor Tetiana Zakharivna Moskalets for close scientific cooperation in the field of wheat breeding and assistance in providing professional advice on the problems of the study.

CONFLICT OF INTEREST

None.

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Створення вихідного матеріалу у результаті залучення різних різновидностей пшениці м'якої озимої в селекції на адаптивність, продуктивність і якість зерна

Валентин Віталійович Москалець

Доктор сільськогосподарських наук, старший науковий співробітник
Інститут садівництва Національної аграрної академії наук України
03027, вул. Садова, 23, с. Новосілки, Україна
https://orcid.org/0000-0002-0831-056X

Світлана Петрівна Коцюба

Кандидат сільськогосподарських наук, доцент
Уманський національний університет садівництва
20300, вул. Інститутська, 1, м. Умань, Україна
https://orcid.org/0009-0000-0949-376X

Жанна Миколаївна Новак

Кандидат сільськогосподарських наук, доцент
Уманський національний університет садівництва
20300, вул. Інститутська, 1, м. Умань, Україна
https://orcid.org/0009-0005-5046-9370

Віталій Григорович Крижанівський

Кандидат сільськогосподарських наук, доцент
Уманський національний університет садівництва
20300, вул. Інститутська, 1, м. Умань, Україна
https://orcid.org/0000-0001-9803-6893

Ольга Віталіївна Яременко

Кандидат геологічних наук
Поліський національний університет
10002, вул. Старий бульвар, 7, м. Житомир, Україна
https://orcid.org/0000-0002-2882-4621

Анотація. Актуальність даної теми полягає у постійному прагненні до вдосконалення і покращення сортів пшениці м'якої озимої шляхом використання різних генетичних ресурсів і селекційних методів для досягнення кращої адаптивності, вищої продуктивності і вишуканої якості зерна. Мета роботи полягала в розширенні генетичного різноманіття пшениці м'якої озимої, що поєднує в собі високу продуктивність і якість адаптивність для подальшої селекції у контексті продовольчої безпеки. У дослідженнях використані загальноприйняті методики та їх модифікації, що забезпечили високу об'єктивність одержаних результатів. Фенологію, морфологічні дослідження, оцінку селекційного матеріалу за господарсько-цінними ознаками проводили згідно методики проведення експертизи сортів рослин. З'ясовано, що залучення зразка Ferrugineum 1239 до схрещування дозволяє сформувати гібридний матеріал з підвищеною стійкістю проти несприятливих абіотичних чинників довкілля, що відмічено на посівах селекційних номерів 0284/18/1, 0135/18, 0209/18/1 та ін. Доведено, що з урахуванням характеру успадкування та збереження ознак елементів продуктивності колоса на рівні кращих батьківських компонентів у комплексі з високими кількісними ознаками кількості зерен з головного колоса, маси зерен з головного колосу, маси 1000 зерен у гібридних популяцій першого покоління вищезазначені комбінації схрещувань *Triticum aestivum* var. *erythrospermum* з *Triticum aestivum* var. *barbarossa*, *Triticum aestivum* var. *erythrospermum* з *Triticum aestivum* var. *Ferrugineum* можуть бути цінними в селекції пшениці м'якої озимої. Практична цінність роботи полягає в тому, що результати досліджень розширюють відомості про використання в селекції на продуктивність і якість пшениці м'якої озимої різновидностей еритроспермум і лютесценс інших різновидів пшениць м'якої: *Triticum aestivum* var. *barbarossa* і *Triticum aestivum*var. *ferrugineum*. В результаті досліджень кращі зразки (F_4) передані на Носівську селекційно-дослідну станцію для подальшої селекційної роботи

Ключові слова: пшениця м'яка озима; різновидності; *erithrospermum* Körn.; *lutescens* Alef.; *ferrugineum* Alef.; *barbarossa* Alef.; селекція; нові гібридні форми; оцінювання

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 26(7), 79-94

UDC 635.652-044.332:631.461.5
DOI: 10.48077/scihor7.2023.79

Agrobiological assessment of green bean varieties by adaptability, productivity, and nitrogen fixation

Viacheslav Yatsenko*
PhD, Senior Lecturer
Uman National University of Horticulture
20301, 1 Instytutska Str., Uman, Ukraine
https://orcid.org/0000-0003-2989-0564
Serhii Poltoretskiy
Doctor of Agricultural Sciences, Professor
Uman National University of Horticulture
20301, 1 Instytutska Str., Uman, Ukraine
https://orcid.org/0000-0003-3334-0880
Nataliia Yatsenko
Doctor of Agricultural Sciences, Associate Professor
Uman National University of Horticulture
20301, 1 Instytutska Str., Uman, Ukraine
https://orcid.org/0000-0003-3752-314X
Nataliia Poltoretska
Candidate of Agricultural Sciences, Associate Professor
Uman National University of Horticulture
20301, 1 Instytutska Str., Uman, Ukraine
https://orcid.org/0000-0001-9879-1872
Oleksandr Mazur
Candidate of Agricultural Sciences, Associate Professor
Vinnytsia National Agrarian University
21008, 3 Sonyachna Str., Vinnytsia, Ukraine
https://orcid.org/0000-0002-2237-5116

Article's History:
Received: 29.04.2023
Revised: 21.06.2023
Accepted: 10.07.2023

Abstract. Beans should be studied as an ecological object that can be used to replenish the reserves of nitrogen compounds in the soil and increase its biological activity. The goal was to conduct scientifically based zoning of varieties and assess their adaptive and productive potential in terms of productivity and nitrogen fixation. The study was conducted in the training and production department of the Uman National University of Horticulture during 2020-2022, using six varieties common in production. Standard methods of genetic and statistical analysis were used to investigate the parameters of

Suggested Citation:
Yatsenko, V., Poltoretskiy, S., Yatsenko, N., Poltoretska, N., & Mazur, O. (2023). Agrobiological assessment of green bean varieties by adaptability, productivity, and nitrogen fixation. *Scientific Horizons*, 26(7), 79-94. doi: 10.48077/scihor7.2023.79.

*Corresponding author

adaptive variability. The study of phenological changes showed that, depending on the variety, it takes from 54 to 67 days before the onset of technical ripeness, and the variation of this trait is 8%. The shortest period before harvesting green beans was characterised by the varieties Zorenka and Casablanca. The variation of the growing season before the onset of biological ripeness was in the range of 90-108 days (CV=6%). According to the indicator of attachment of the lower bean, suitable varieties for mechanised harvesting were identified – Zorenka and Casablanca. Analysing the parameters of adaptability of the "bean weight" and "yield" indicators, a stable variety was found – Fruidor and highly productive varieties of intensive type Paloma, Laura, Zorenka, and Casablanca. The most productive variety was Zorenkya – 12.7 t/ha, and the least productive – Fruidor – 1.9 t/ha. In terms of seed yield, the varieties Purpurova Koroleva, Zorenka, and Casablanca stood out, the yield of which was at the level of 2.22-2.89 t/ha, which is 30.8-70.6% more than the standard. Analysing the dependence of the growth and development parameters of green bean plants, it can be seen that these traits depend more on the conditions (CVA, %) in which they were formed than on the genotypic component (CVG, %). The results obtained provide useful information on commercial and seed production, productivity and the nitrogen-fixing ability for introduction into industrial production or further breeding practice and prove that green bean varieties are suitable for both vegetable production and high-quality seeds, as well as for biologisation of production through the use of biologically fixed nitrogen

Keywords: *Phaseolus vulgaris*; nitrogen fixation; nutritional value; performance; protein; soluble sugars

INTRODUCTION

A promising task of growing green bean pods in unstable conditions of moistening of the Ukrainian Forest-Steppe is the introduction of elements of adaptive varietal technology for growing crops, since varieties as a dynamic biological system belong to one of the main places in solving the problem of yield growth. According to the FAO (State register..., 2023) legumes in world agriculture occupy about 15% of the acreage. The leading position is occupied by green bean pods (sugar or vegetable). The acreage of crops in the world over the past 10 years has grown by 200 thousand hectares and amounts to almost 30 million hectares.

Research conducted by Baruah *et al.* (2022), to assess the productivity of green beans in five different agroclimatic zones of India, aimed to assess the signs of growth, yield, and consumer preferences for organoleptic indicators and cost-effectiveness of cultivation. Among the three varieties, it was found that Arka Sukomal significantly exceeds most of the studied characteristics, such as the longest duration of the growing season (98 days), the maximum number of beans per plant (62.86) and the largest bean weight (13.18 g) and the highest yield (20.75 t/ha).

Thapa *et al.* (2022) note that when studying green bean varieties, the plant height was highest in Semi long ligh (332 cm) and lowest in Trishuli (294.48 cm). The total number of seeds was highest in Semi Long Green – 8.6 and lowest in Trishuli – 7. The highest yield was found in Trishuli – 2.69 t/ha, then Chaumase – 2.56 t/ha, Semi long green – 2.33 t/ha, and the lowest was in Semi Long Light – 1.51 t/ha. Analysing the results of the above-mentioned researchers, it can be seen that the research focused on tall (climbing) varieties of green beans, where an inverse relationship between plant height and yield can be traced, which is consistent with the results of Rinku & Sibani (2014) studies conducted with bush forms of green beans.

Mazur *et al.* (2017) and Mazur *et al.* (2020) studied the parameters of adaptive ability in the conditions of the Forest-Steppe of Ukraine and noted that the variety is the basis of cultivation technology, it is very difficult to combine the high weight of 1,000 grains with the stability of this indicator. Seed yield and the constituent structure of the crop are quantitatively inherited and highly dependent on the environment (Olifirovich & Olifirovich, 2020), so understanding the relationship between the crop and its components is important for establishing effective criteria for selection and seed production. Several studies of beans have found high correlations between yield and weight of 100 seeds, yield and number of beans and seeds per plant (Beebe *et al.*, 2013; Assefa *et al.,* 2015; Rao *et al.,* 2017). Thus, the components of the crop structure were used as selection criteria to improve grain yield.

The potential of green beans as a fresh vegetable is not fully used and is not produced in sufficient quantities to meet the needs of the population. A high yield can be achieved by selecting varieties that have high adaptability. The selection of this feature invariably affects a number of related features, which makes it necessary to determine the relationships between various performance components (Alice *et al.,* 2018, Reddy *et al.,* 2021, Bala *et al.,* 2022).

The purpose of this study was to identify varietal features of the development of parameters of adaptive capacity of green beans by indicators of the weight of pods, g/plant; yield of pods and seeds, t/ha; parameters of the nutritional value of the pods; development and functioning of the nodulation apparatus.

MATERIALS AND METHODS

The research was conducted at the experimental sites of the Department of vegetable growing, in the training and production department of the Uman National

University of Horticulture in 2020-2022, with geographical coordinates in Greenwich Mean Time 48˚46' N, 30˚14' E and an altitude of 245 m above mean sea level.

The soil of the experimental site is podzolic heavy loamy chernozem (World reference base for soil resources, 2014). The Uman weather station served as the database of meteorological data. The analysis of the presented data on air temperature and precipitation during the research period was generally characterised as favourable for the growth and development of soybeans. The weather conditions of the 2021-2022 agricultural year were characterised by a significantly lower level of precipitation compared to previous years and the average annual data, and the temperature regime was close to the average annual data. In general, weather conditions significantly affected the formation of productivity of vegetable soybeans. The growing season of 2020 was quite favourable for the growth and development of vegetable soybean plants, as it had a sufficient amount of precipitation and, accordingly, a sufficient amount of productive moisture reserves in the soil, which created optimal conditions from seed germination to the beginning of bean filling. Thus, the growing season of plants for 2021 was characterised as the most favourable due to a large amount of precipitation, especially during the flowering-bean filling phase. The growing season of 2022 was characterised as unfavourable for the growth and development of vegetable soybeans due to prolonged droughts and insufficient precipitation during critical periods and the phase of bean filling, respectively, the phenomenon of bean abortisation (Novak & Novak, 2021, 2022).

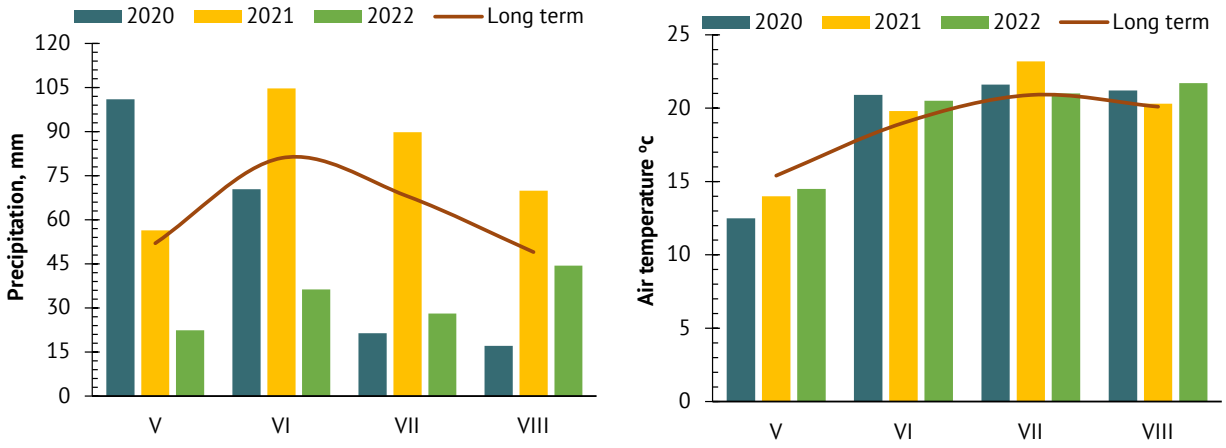

Figure 1. *Climate map for the research period (2020-2022)*

Biometric measurements (number of shoots, pcs./plant; number of beans per plant, and number of seeds, pcs./pod) and indicators of individual productivity (weight of beans, g/plant, seed weight, g/plant) were performed on 100 typical plants. All measurements and studies were carried out in the phase of technical ripeness of beans (harvesting) – BBCH (Biologische Bundesanstalt, Bundessortenamt and CHemical industry), seed yield was determined in the BBCH 99 phase.

Research on the adaptive and productive potential of green bean varieties was carried out according to the scheme, which included seven variants of green bean varieties: Paloma, Fruidor, Purpurova Koroleva, Laura, Zorenka, Casablanca, which were grown according to generally accepted technology. The standard (st) is the Laura variety because, at the time of research, it was the most tested and was the longest in the State register of plant varieties suitable for dissemination in Ukraine (State register of plant varieties suitable for dissemination in Ukraine, 2023).

The experiments were set up systematically, without repetition. The area of the experimental plot – 10 m^2. Bean seeds were sown in the second ten days of April according to the 45×10 cm scheme (222,000 pcs./ha). The predecessor of green beans in the experiment was winter garlic.

The leaf area was determined by the "notching" method using the equation:

$$S = \frac{K+Y}{P} * B, \quad (1)$$

where: S – leaf surface area, cm^2; K – number of notches; Y – area of one notch, cm^2; P – weight of notches, g; B – weight of leaves, g.

Yield accounting was carried out in accordance with DSTU OOFFV-06 (2007) – by the method of dividing weighing during the period of technical ripeness with the division of products into standard and non-standard

The average weight of beans and green bean fruits was determined by the true weight method. Determination of the biochemical composition of green bean pods was carried out in the laboratory of mass analysis of the Uman National University of Horticulture.

Sugars were extracted from the ground (1 g) unripe beans with water and analysed using high-performance liquid chromatography (HPLC) using the HPLC Waters-2695 chromatrograph. Sugar content measurements

were determined using a waters 410 differential refractometer using the method by Johansen *et al.* (1996):

- dry residue in beans – drying at 105°C in the drying cabinet SNOL58/350A according to DSTU 7804:2015 (2015);

- protein content – by the Kjeldahl method, in accordance with DSTU ISO 5983-2003 (2003);

- content of nitrates and nitrites – by spectrometric method according to DSTU ISO 6635: 2004 (2004);

- the number and weight of rhizobia on plant roots and the content of legoglobin (leghemoglobin) were determined according to G.S. Posypanov (1991), the amount of fixed nitrogen – according to Unkovich *et al.* (2008). To determine symbiotic productivity, the parameters of the total and active symbiotic potential (TSA) were used, which was calculated by the equation:

$$TSA = M_1 + M_2 T, \quad (2)$$

where: T – period between two adjacent analysis dates, days; M_1+M_2 – average weight of nodules with legoglobin for the period T, kg/ha.

Genetic and statistical processing of results

To systematise the results, the authors used a rank classification of genotypes based on the ratio of plasticity (bi) and stability parameters $\sigma^2 d$: 1) bi<1, $\sigma^2 d$>0 – shows the best results under unfavourable conditions, unstable; 2) bi<1, $\sigma^2 d$=0 – shows the best results under unfavourable conditions, stable; 3) bi=1, $\sigma^2 d$=0 – responds well to improved conditions, stable; 4) bi=1, $\sigma^2 d$>0 – responds well to improved conditions, unstable; 5) bi>1, $\sigma^2 d$=0 shows better results under favourable conditions, stable; 6) bi>1, $\sigma^2 d$>0 – shows the best results under favourable conditions, unstable. Genotypes with a coefficient bi>1 belong to high-plastic (relative to the average group), and for 1>bi=0 – to relatively low-plastic (*Finlay & Wilkinson,* 1963; *Eberhart & Russell,* 1966).

Homeostasis (variation of the trait) of varieties (Hom) was calculated by the equation:

$$H_{om} = \frac{\overline{X^2}}{\sigma}, \quad (3)$$

where: $\bar{X}$ – arithmetic mean by variety; σ – generalised mean square deviation.

The breeding value of the variety was determined by the equation:

$$(Sc) = \bar{X} \times \frac{\bar{X}_{lim}}{\bar{X}_{opt}} \quad (4)$$

$\bar{X}$ – arithmetic mean by variety; $\bar{X}_{lim}$ – limited arithmetic mean; $\bar{X}_{opt}$ – optimal arithmetic mean.

The multiplicativity coefficient (MC) was used to avoid a linear artefact of the regression coefficient, which allows comparing the variability of the feature:

$$MC = \frac{\overline{Xi} + bi \cdot yi}{Xi}, \quad (5)$$

where $\bar{X}i$ – average value of the studied feature in *i*-th variety; *bi* – linear regression coefficient of *i*-th variety; *yi* – average value for all averages for all varieties *yi* for each *j*-th point of the experiment.

The ecological plasticity index was calculated by the equation:

$$EPI = \frac{\left(\frac{UV_1}{SUO_1} + \frac{UV_2}{SUO_2} + \cdots + \frac{UV_n}{SUO_n}\right)}{n}, \quad (6)$$

where UV_1, UV_2, UV_n – value of the variety indicator in different years of testing; SUO_1, SUO_2, SUO_n – average value of the variety indicator in each of the experiment variants.

The annual adaptability coefficient (AC) was calculated using the equation:

$$AC = \frac{(Xij) \times 100 \times X)}{100}, \quad (7)$$

where Xij – yield of a certain variety in the year of testing; X –average variety yield of the year.

The absolute average adaptability coefficient (AAC) is calculated for the variety using the equation:

$$AAC = \frac{(XiC) \times 100 \times Xb)}{100}, \quad (8)$$

where XiC – average yield of the variety over the years of research, Xb – long-term average variety yield.

Stress resistance and compensatory ability of varieties were determined according to *Rossielle & Hemblin* (1981):

$$SR = Y_{min} - Y_{max} \quad (9)$$

$$CA = \frac{Y_{min} + Y_{max}}{2}, \quad (10)$$

where Y_{min} and Y_{max} – minimum and maximum values of the variety indicator.

In experiments, the phenotypic, genotypic, and ecological variability of varieties was determined using the following equations:

Genetic variance:

$$\sigma_G^2 = \frac{CM_p - CM_e}{r}; \quad (11)$$

Ecological variance:

$$\sigma_A^2 = CM_e; \quad (12)$$

Phenotypic variance:

$$\sigma_F^2 = \sigma_G^2 + \sigma_A^2.$$

Coefficient of genotypic variation:

$$\frac{\sqrt{\sigma_G^2 \times 100}}{\bar{X}}; \quad (13)$$

Coefficient of phenotypic variation:

$$\frac{\sqrt{\sigma_F^2 \times 100}}{\bar{X}}; \quad (14)$$

Coefficient of ecological variation:

$$\frac{\sqrt{\sigma_A^2 \times 100}}{\bar{X}}, \quad (15)$$

where CM_p – generalised root-mean-square value of the population trait; CM_e – generalised root-mean-square error, r – number of repetitions.

Statistical processing of the obtained results was performed with the calculation of the arithmetic mean (x) of standard deviation (SD) calculated using Microsoft Excel 2019. Correlation dependencies were determined using the Statistica 12 software suite.

RESULTS AND DISCUSSION

Observations show that modern bean varieties are characterised by different growing seasons (60-180 days), which is conditioned by genetic characteristics. The speed of passing the main stages of organogenesis is important in the cultivation of crops. The faster the bean plants finish forming the vegetative mass and move on to fruiting, the longer the period of harvesting the pods. According to the "International classifiers of the CMEA for cultivated species *Phaseolus* L. the study included two groups of varieties – medium-early (51-55) and medium-ripening (61-70 days from germination to technical ripeness) (Fig. 2).

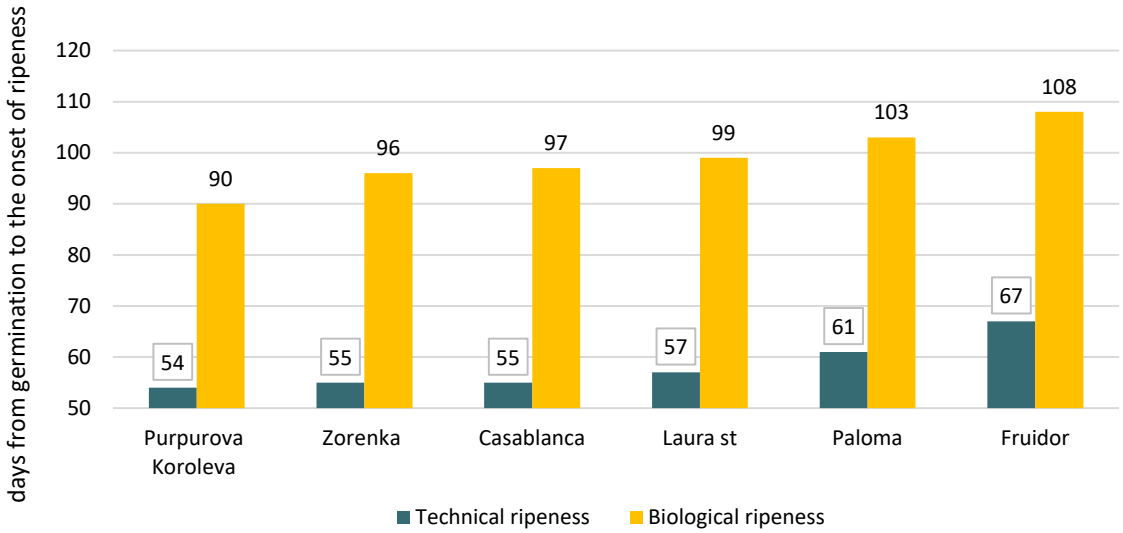

Figure 2. *Duration of periods from the germination to the onset of technical/biological ripeness of green bean varieties (2020-2022)*

Source: *obtained as a result of author's research*

Studies have established that the period from germination to the onset of technical ripeness of green bean varieties was 54-67 days, CV=8%. The shortest period before the onset of technical ripeness was characterised by the Purpurova Koroleva variety – 54 days, and the Zorenka and Casablanca varieties – 55 days.

The variation of the period from the germination to the onset of biological ripeness was 6% and was in the range of 90-108 days. The dynamics of the onset of biological ripeness remained the same as in the previous sign. Earlier-maturing varieties were Purpurova Koroleva – 90 days, and Zorenka and Casablanca – 96 and 97 days, respectively.

A study of the height of green bean plants showed that on average, the varieties differed significantly over the years. Thus, the highest were plants of the standard Laura and Paloma varieties – 49.7 and 49.3 cm, respectively. Plants of the Zorenka, Fruidor, and Casablanca varieties were 2.3-6.0 cm lower (4.7-12.1%). The Purpurova Koroleva variety can be attributed to the dwarf type, since the height of its plants was 40.7 cm, which is 9 cm less than the Laura variety (18.1%).

The suitability of the variety for mechanised harvesting depends on the height of attachment of the first bean, so this indicator was also considered. Thus, the lowest attachment of the first bean was observed in the varieties Purpurova Koroleva – 11.3 cm and Fruidor – 12.3 cm, and the highest in the variety Laura – 15.3 cm, but the beans of the varieties Purpurova Koroleva and Fruidor were tightly collected in internodes, while the variety Laura had more internodes and it is suitable for manual harvesting in several samples. Other varieties under study had a height of 1st bean attachment of 14.0-15.7 cm, which characterises them as varieties suitable for mechanised harvesting.

Among legumes, beans occupy one of the first places in terms of the variety of morphological features and their amplitude. This is due to its strong plasticity and high adaptability to growing conditions. Bean plants can form an area of leaves under optimal conditions up to 36-38 thousand m^2/ha. Other data indicate that the intensity of photosynthetic activity of beans can reach 4-5 $m^2/1m^2$. The productivity of the plant and sowing in general depend on a properly developed leaf apparatus

and its functioning. Thus, the largest leaf area was developed by varieties of green beans Paloma (24.1 thousand m^2), Casablanca (27.3 thousand m^2), and Zorenka (28.1 thousand m^2), which is 5.1-22.7% more than the standard. A smaller area of the assimilation surface by 0.4% was formed by the Fruidor variety (Table 2).

Table 1. *Growth and development parameters of various varieties of green beans (2020-2022), (Lim±SD) (BBCH 75)*

Variety	Leaf area of crops, thous. m^2		Plant height, cm		Height of attachment of 1-st bean	
	Lim±SD	CV, %	Lim±SD	CV, %	Lim±SD	CV, %
Paloma	16.1-30.4±6.0	25	44-54±4.1	8	11-16±2.2	15
Frouidor	15.4-28.2±5.3	24	40-50±4.3	9	11-14±1.2	10
Purpurova Koroleva	18.8-28.0±3.8	16	37-45±3.3	8	10-12±0.9	8
Laura st	15.5-28.8±5.5	24	44-54±4.2	8	12-18±2.5	16
Zorenka	22.1-33.7±4.7	17	45-50±2.1	4	13-18±2.1	13
Casablanca	23.0-31.8±3.6	13	40-48±3.3	8	13-16±1.2	9
Xmed.	24.8		46		13.9	
σ_G^2	8.0		4.4		1.1	
σ_F^2	36.8		27.6		6.7	
σ_A^2	28.8		23.2		5.7	
CVG, %	11.4		4.5		7.4	
CVF, %	24.5		11.4		18.7	
CVA, %	21.7		10.4		17.1	
CVG/CVA	0.53		0.44		0.43	

Note: ** – st – standard*
Source: *obtained as a result of author's research*

Analysing the dependence of the growth parameters of green bean plants, it can be seen that these traits are more dependent on the conditions (CVA=21.7, 10.4 and 17.1%) in which they were formed, rather than on the genotypic component (CVG=11.4; 4.5 and 7.4%, respectively, according to the attribute). According to the number of shoots on the plant, a high bushiness index was noted in varieties Laura, Fruidor, and Casablanca – 3-8 shoots/plant. A dense, erect bush with a small number of shoots had varieties Purpurova Koroleva, Paloma, and Zorenka – 3-5 pcs./plant. A large number of beans on the plant were characterised by varieties Purpurova Koroleva and Paloma – 12.3 and 13.0 pcs., respectively. Zorenka varieties had a smaller number of beans than the standard (10 pcs.), Casablanca (9.3 pcs.) and Fruidor (5.7 pcs.), which is 9.1-48.5% less. According to the number of shoots and beans on the plant, the coefficient of variation of the environment (CVA) was in high limits – 31.9 and 35.8%, and the relationship between the coefficient of genetic and ecological variation (CVG/CVA) was noticeable (0.47 and 0.44), which indicates very favourable environmental conditions for growing this crop (Table 2).

Table 2. *Parameters of individual productivity of different varieties of green beans (2020-2022), (Lim±SD) (BBCH 75)*

Variety	Number of shoots, pcs./plant.		Number of beans, pcs./plant	
	Lim±SD	CV, %	Lim±SD	CV, %
Paloma	3-5±0.82	20	8-18±4.2	34
Frouidor	3-7±1.63	33	5-6±0.5	8
Purpurova Koroleva	3-4±0.47	13	11-15±1.6	13
Laura st	4-8±1.70	27	7-16±3.7	34
Zorenka	3-5±0.94	22	8-14±2.8	28
Casablanca	3-6±1.25	27	8-12±1.9	20

Table 2, Continued

Variety	Number of shoots, pcs./plant.		Number of beans, pcs./plant	
	Lim±SD	CV, %	Lim±SD	CV, %
Xmed.	4.7		10.2	
σ_G^2	0.5		2.6	
σ_F^2	2.7		16.0	
σ_A^2	2.2		13.4	
CVG, %	15.1		15.6	
CVF, %	35.3		39.1	
CVA, %	31.9		35.8	
CVG/CVA	0.47		0.44	

Note: ** – st – standard*
Source: *obtained as a result of author's research*

According to the weight of green beans on the plant, the varieties Zorenka (59.7 g), Casablanca (38.0 g), and Paloma (31.7 g) and Purpurova Koroleva (31.7 g) were larger than the standard by 8.0-103.4%, or 2.3-30.0 g. The Fruidor variety was characterised by a lower indicator relative to the standard by 68.2% (Table 3).

Table 3. *Parameters of adaptive capacity and breeding value of vegetable bean varieties based on "bean weight", g/plant. (BBCH 75)*

Variety	Xmed, g/plant	$\sigma^2 d$	bi	Hom	Sc	MC	EPI	SR	CC	KAA
Paloma	31.7	3.39	1.10	51.1	2.6	14.38	0.93	-27	30	0.95
Frouidor	9.3	0.69	0.01	4.4	0.8	1.37	0.31	-1	10	0.04
Purpurova Koroleva	31.7	2.12	0.35	51.0	2.6	5.25	1.04	-10	33	2.14
Laura st	29.3	3.33	1.06	43.8	2.4	14.97	0.86	-26	27	0.08
Zorenka	59.7	4.90	2.30	181.2	4.9	15.88	1.73	-58	57	1.07
Casablanca	38.0	3.52	1.18	73.5	3.1	13.00	1.13	-29	36	0.09
Xmed	33.3									
σ_G^2	55.7									
σ_F^2	441.7									
σ_A^2	386.0									
CVG, %	22.4									
CVF, %	63.1									
CVA, %	59.0									
CVG/CVA	0.38									

Note: ** – st – standard*
Source: *obtained as a result of author's research*

Genetic and statistical analysis of this indicator has shown that the most stable (in terms of indicators $\sigma^2 d$ and MC, Hom) was the Fruidor variety. By indicators of the ratio of plasticity parameters (*bi*) and stability $\sigma^2 d$ varieties Paloma, Laura, Zorenka, and Casablanca had a ratio of indicators $bi>1$, $\sigma^2 d>0$ – that is, they have better results under favourable growing conditions. Varieties Fruidor and Purpurova Koroleva had a ratio of indicators $bi<1$, $\sigma^2 d>0$, i.e., they had better results under unfavourable conditions and were unstable.

According to the indicator of stress resistance (SR), the Zorenka variety stood out, which indicates its high productivity in optimal growing conditions. In terms of compensatory capacity (CC), the varieties under study were characterised by a significant variation, but the Zorenka and Kasalanka varieties had the highest

indicators of this parameter, which allows them to be attributed to the group of plastic-type varieties.

On the basis of "seed weight" in terms of absolute adaptability, the most adaptive varieties with an adaptability coefficient (AC) of more than 1 were identified – Purpurova Koroleva and Zorenka. The Paloma variety is medium-adaptive and the Fruidor, Laura and Casablanca varieties are marked as low-adaptive. Low productivity of bean varieties is confirmed by high exposure to external conditions (CVA=59.0%) and low CVG/CVA=0.38 ratio.

The yield of green beans (pods) consists mainly of two structural elements – the number of plants per unit area and the weight of beans per plant. The "pod yield" attribute varied on average from 1.9 to 12.7 t/ha (by year from 1.8 t/ha (2022) for the Fruidor variety to 19.35 t/ha (2021) for the Zorenka variety). The yield of green bean varieties depended not only on the varietal characteristics of plants, but also on weather conditions. In the years with optimal water supply (2020-2021), this indicator reached its theoretical maximum, and in 2022 – a minimum.

According to the "pod yield", the varieties Zorenka (12.72 t/ha), Casablanca (8.05 t/ha), Paloma (6.74 t/ha), and Purpurova Koroleva (6.87 t/ha) were higher than the standard by 9.8-107.1%, or 0.6-6.6 t/ha. The Fruidor variety was characterised by a lower indicator relative to the standard by 68.4%, or 4.2 t/ha (Table 4).

Table 4. *Parameters of adaptive capacity and breeding value of green bean varieties based on "green bean yield", t/ha (BBCH 75)*

Variety	Xmed. t/ha	$\sigma^2 d$	bi	Hom	Sc	MC	EPI	SR	CC	KAA
Paloma	6.7	1.61	1.06	10.4	2.4	3.99	0.93	-6	6	0.95
Frouidor	1.9	0.31	0.04	0.9	0.7	1.37	0.31	0	2	0.19
Purpurova Koroleva	6.9	0.98	0.35	10.8	2.5	1.97	1.08	-2	7	2.17
Laura st	6.1	1.61	1.04	8.6	2.2	4.24	0.83	-6	6	0.32
Zorenka	12.7	2.35	2.26	37.0	4.6	4.39	1.73	-14	13	4.20
Casablanca	8.1	1.76	1.26	14.8	2.9	3.99	1.12	-7	8	0.36
Xmed	7.1									
σ_G^2	3.0									
σ_F^2	22.1									
σ_A^2	19.1									
CVG, %	24.6									
CVF, %	66.5									
CVA, %	61.8									
CVG/CVA	0.40									

Note: ** – st – standard*
Source: *obtained as a result of author's research*

Genetic and statistical analysis of this indicator has shown that the most stable (in terms of indicators $\sigma^2 d$ and MC, Hom) was the Fruidor variety. By indicators of the ratio of plasticity parameters (*bi*) and stability $\sigma^2 d$ varieties Paloma, Laura, Zorenka, and Casablanca had a ratio of indicators $bi>1$, $\sigma^2 d>0$ – that is, they have better results under favourable growing conditions. The Fruitor variety had a ratio of indicators $bi<1$, $\sigma^2 d > 0$, i.e., have better results under unfavourable conditions, unstable. The Purpurova Koroleva variety had a ratio of bi=1, $\sigma^2 d>0$ – responds well to improved conditions, unstable

According to the coefficient of ecological plasticity, the group of high-plastic varieties includes Paloma, Laura, Zorenka, and Casablanca; the group of low-plastic varieties includes Fruidor and Purpurova Koroleva.

According to the indicator of stress resistance (SR), the Zorenka variety stood out, which indicates its high productivity in optimal growing conditions. In terms of compensatory capacity (CC), the studied varieties were characterised by a significant variation, but the varieties Zorenka, Casablanca, Laura, and Paloma had the highest indicators of this parameter, which allows them to be attributed to the group of plastic-type varieties.

On the basis of "pod yield" in terms of absolute adaptability (AA), the most adaptive varieties with an adaptability coefficient (AC) of more than 1 were identified – Purpurova Koroleva and Zorenka. The Paloma variety belongs to the medium-adaptive and the Fruidor, Laura, and Casablanca varieties are classified as

low-adaptive. The low productivity of bean varieties is confirmed by the high influence of external conditions (CVA=61.8%) and the low CVG/CVA=0.40 ratio.

Seed yield consists mainly of two elements of productivity: the number of plants per unit area and the weight of seeds per plant. The parameters of this attribute on average were in the range of 0.47-2.89 t/ha (by year: from 0.33 t/ha in 2022 to 3.78 t/ha in 2021). In terms of seed yield, the varieties Purpurova Koroleva, Zorenka, and Casablanca stood out, the yield of which was at the level of 2.22-2.89 t/ha, which is more than the standard by 30.8-70.6 % or 0.5-1.2 t/ha (Table 5).

Table 5. *Parameters of adaptive capacity and breeding value of green bean varieties based on "seed yield", t/ha (BBCH 99)*

Variety	Xmed., t/ha	$\sigma^2 d$	bi	Hom	Sc	MC	EPI	SR	CC	AC
Paloma	1.11	0.50	0.63	1.3	2.6	1.53	0.60	-1	1	0.61
Frouidor	0.47	0.35	0.09	0.2	1.1	1.18	0.26	0	0	0.67
Purpurova Koroleva	2.22	0.55	0.76	5.1	5.3	1.32	1.24	-1	2	2.64
Laura st	1.69	0.71	1.25	3.0	4.0	1.69	0.91	-1	2	1.82
Zorenka	2.89	0.69	1.20	8.6	6.9	1.39	1.60	-1	3	37.70
Casablanca	2.58	0.92	2.07	6.9	6.1	1.75	1.38	-2	3	2.55
Xmed	1.83									
σ_G^2	0.08									
σ_F^2	1.01									
σ_A^2	0.93									
CVG, %	15.2									
CVF, %	55.1									
CVA, %	52.9									
CVG/CVA	0.29									

Note: ** – st – standard*
Source: *obtained as a result of author's research*

Statistical analysis has shown that according to the indicators of the ratio of plasticity parameters (*bi*) and stability $\sigma^2 d$, Laura variety had a ratio of indicators *bi*>1, $\sigma^2 d$>0 – that is, it has better results under favourable growing conditions. Varieties Paloma, Fruidor, Zorenka, and Casablanca had a ratio of indicators *bi* < 1, $\sigma^2 d$>0, i.e., they had better results under unfavourable conditions and were unstable. The Purpurova Koroleva variety had a ratio of bi=1, $\sigma^2 d$>0 – responds well to improved conditions, unstable. According to the coefficient of ecological plasticity, the Laura variety belongs to the group of high-plastic varieties; all other varieties studied belong to the group of low-plastic varieties. Rather low seed productivity of bean varieties is confirmed by the significant influence of external conditions (CVA=52.9%) and a low ratio CVG/CVA=0.29.

According to the indicator of stress resistance (SR), the Casablanca variety stood out, which indicates its high productivity in optimal growing conditions. In terms of compensatory capacity (CC), the varieties under study were characterised by sufficient alignment, but the Zorenka and Casablanca varieties had the highest indicators of this parameter, which allows them to be attributed to the group of plastic-type varieties. On the basis of "seed weight" in terms of absolute adaptability (AA), the most adaptive varieties with an adaptability coefficient (AC) of more than 1 were identified – Purpurova Koroleva, Zorenka, Laura, and Casablanca. Paloma and Fruidor varieties are medium-adaptive.

Vegetable crops, each of which has a unique biochemical composition, make our diet diverse and have a positive effect on health. The biochemical composition of green beans is not constant, it is subject to variability depending on the type and variety, and also varies under the influence of growing conditions.

Studies have shown that green bean varieties were characterised by a low variation in biochemical parameters (CV=1-9%). The sugar content in pods over the years was in the range of 1.91-2.78%. On average, over the years of research, the varieties Purpurova Koroleva (2.60%), Laura, and Fruidor (2.50%) were distinguished by this feature, which were at the standard level and/or exceeded it by 4.0%. Varieties Casablanca, Paloma, and Zorenka accumulated significantly less sugar compared to other varieties and the standard in particular – 2.00-2.40% (Table 6).

Table 6. *Content of individual components of the biochemical composition in the pods of green bean varieties (2020-2022), (X±SD) (BBCH 75)*

Variety	Proportion of sugars, %		Ascorbic acid content, mg/100 g		Nitrate content, mg/kg	
	X ± SD	CV, %	X ± SD	CV, %	X ± SD	CV, %
Paloma	2.10±0.07	3	16.03±1.13	7	148.3±3.7	3
Frouidor	2.50±0.02	3	21.41±1.43	7	145.1±6.4	4
Purpurova Koroleva	2.60±0.06	4	16.20±1.02	6	127.9±6.2	5
Laura st	2.50±0.03	1	16.02±1.42	9	136.3±4.1	3
Zorenka	2.00±0.08	4	13.22±0.91	7	145.8±4.7	3
Casablanca	2.40±0.07	4	14.05±0.89	6	151.2±6.0	4
Xmed.	2.35±0.21		16.20±2.60		148.3±7.96	3
	0.001		0.44		9.4	
	0.049		8.54		100.8	
	0.049		8.10		91.5	
CVG, %	1.47		4.12		2.1	
CVF, %	9.59		18.09		7.0	
CVA, %	9.48		17.61		6.7	
CVG/CVA	0.15		0.23		0.32	

Note: ** – st – standard*
Source: *obtained as a result of author's research*

In terms of ascorbic acid concentration, the variation was average – CV=16%, and the parameters of this trait for years ranged from 11.97-22.57 mg/100 g, depending on the variety. According to the content of ascorbic acid, only one variety was distinguished, which accumulated significantly more than the standard – Fruidor (21.41 mg/100, which is 33.6% more than the standard). The Paloma and Purpurova Koroleva varieties accumulated slightly more ascorbic acid relative to the standard, while the Zorenka and Casablanca varieties had significantly lower ascorbic concentrations.

The concentration of nitrates on average varied little, and over the years ranged from 119.2-159.5 mg/kg, depending on the variety. With a low concentration of nitrates, the Purpurova Koroleva variety was distinguished, where this indicator was lower than the standard variety by 6.2% or 8.4 mg/kg. Varieties Paloma, Fruidor, Zorenka, and Casablanca were characterised by an increased content of nitrates relative to the standard by 7.0-10.9%.

The value of green bean varieties for vegetable purposes lies in the high content of protein and dry matter. In modern conditions, breeding work with green beans should be aimed at meeting the needs of the processing industry, which will expand the area of cultivation of the crop and the scope of its use. In the successful solution of this problem, the leading role belongs to quality selection. Genetic sources and donors of such traits are among the most scarce plant resources. In this regard, a scientifically based selection of green bean varieties with their subsequent introduction into industrial production is extremely important. According to this feature, the varieties Fruidor and Purpurova Koroleva with a protein content of 17.13 and 15.34% were distinguished.

The nutritional value of green beans is high and is conditioned by the content of various minerals, vitamins, macro- and microelements. It is well known that the biochemical composition of beans is not constant and is influenced by many factors. Studies have shown that the dry matter content was stable both in varieties individually (CV=3-5%) and over the years (CV=9%). In terms of "dry matter content", only one variety was distinguished – Paloma, in which this indicator was at the level of 11.00% and the standard prevailed by 22.2%. In the course of experimental studies, it was found that the protein content varied greatly in the range of 18-21% for varieties and 12% for years.

With an increased protein content, two varieties were identified – Fruidor (17.13%) and Purpurova Koroleva (15.34%), which exceeded the standard by 17.3 and 5.0%, respectively, which characterises them as promising sources of signs of nutritional value for breeding. Statistical processing data indicate a strong influence of environmental conditions on the formation of nutritional value parameters (CVA=9.23-24.24%, and CVG/CVA=0.21-0.52, although to obtain high productivity indicators, the CVG/CVA ratio must be close

to 1. All presented varieties are recommended for use as sources of high taste qualities; suitable for canning and freezing; creating a conveyor of green beans (Table 7).

With a high content of carbohydrates and fats, two varieties are distinguished – Fruidor and Purpurova Koroleva. The conditional protein yield in the technical ripeness phase varied at 33%, in the biological ripeness phase – at the level of 42%, which confirms a strong differentiation of varieties according to the parameters of the biochemical complex. (Fig. 2).

Table 7. *Nutritional value of the pods of different green bean varieties (2020-2022), (X±SD) (BBCH 75)*

Variety	Dry matter, %	Protein, %	Carbohydrates	Fats	Energy, kcal. 100 g dry matter
			g/100 g dry matter		
Paloma	11.00±0.30	14.05±2.77	6.87±1.38	3.36±0.83	113.92±24
Frouidor	9.00±0.23	17.13±3.20	8.23±1.53	3.96±0.79	137.10±26
Purpurova Koroleva	9.30±0.49	15.34±3.06	7.70±1.51	3.71±0.86	125.53±26
Laura st	9.00±0.30	14.60±3.01	7.30±1.51	3.55±0.80	119.55±25
Zorenka	8.60±0.35	11.33±2.05	5.73±0.95	2.90±0.54	94.36±17
Casablanca	8.80±0.25	13.37±2.34	6.70±1.10	3.15±0.68	108.67±20
Xmed	9.30	14.30	7.09	3.44	
σ_G^2	0.03	2.56	0.61	0.19	
σ_F^2	0.77	13.37	3.05	0.89	
σ_A^2	0.73	10.82	2.45	0.70	
CVG, %	1.97	11.18	10.99	12.70	
CVF, %	9.44	25.57	24.65	27.37	
CVA, %	9.23	22.99	22.07	24.24	
CVG/CVA	0.21	0.49	0.50	0.52	

Note: ** – st – standard*
Source: *obtained as a result of author's research*

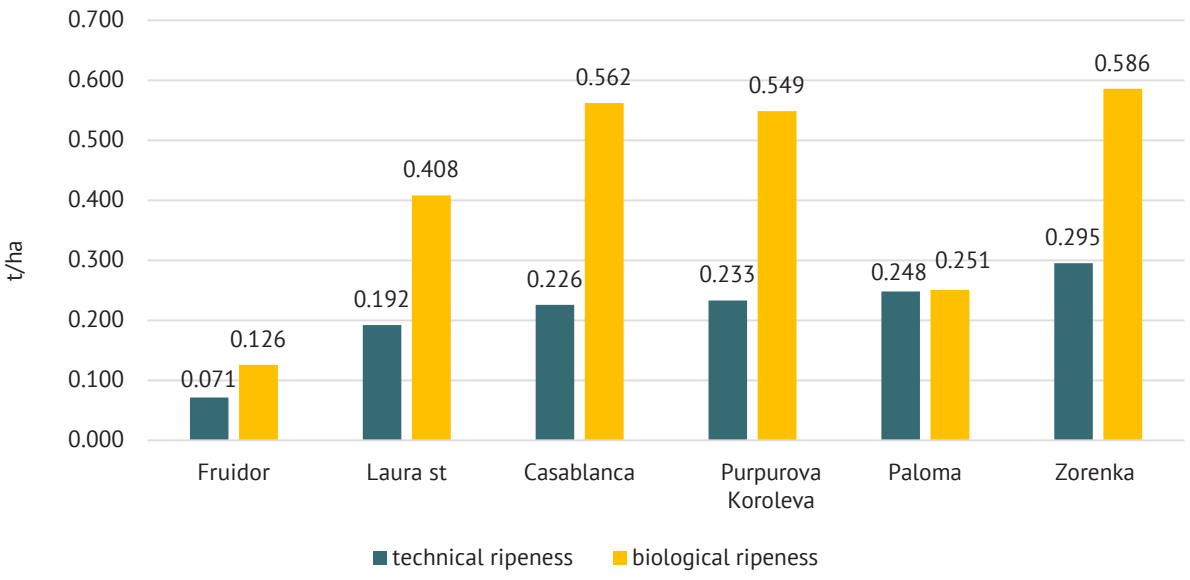

Figure 2. *Conditional protein yield from pods and mature green bean seeds depending on the variety (2020-2022), t/ha*
Source: *obtained as a result of author's research*

Thus, according to this feature, in the phase of technical ripeness of green bean pods, the Zorenka variety was distinguished with a maximum protein yield of 0.295 t/ha. In general, all the varieties under study, except for the Fruidor variety, prevailed over the standard. In the phase of biological ripeness, the dynamics were similar, but most varieties increased this indicator by 98.55-149.19%, and the Paloma variety by only 1.03%. In the phase of biological ripeness, according to the indicator of conditional protein yield, Casablanca, Purpurova Koroleva, and Zorenka varieties were identified, where this indicator was at the level of 0.549-0.586 t/ha.

From the results shown in Table 8, it can be seen that the varieties Paloma, Fruidor, and Casablanca formed the largest **total** number of nodules on one plant – 14.0-16.3 pcs./plant, all other varieties formed from 7.7 to 12.7 pcs./plant, which was significantly less than the above-mentioned varieties. By number of **active nodules** the same varieties (Paloma, Fruidor, Casablanca) stood out – 7.0-8.0 pcs./plant. In other varieties, this indicator ranged from 4.3-6.7 pcs./plant of active nodules.

The study revealed that the largest weight of **active** nodules (with legoglobin content) were formed by varieties Paloma, Fruidor, and Laura – 0.09 g/plant, in other varieties the weight of **active** nodules was in the range of 0.05-0.08 g/plant, which was 40.0-41.6% of the total weight of nodules. Thus, in the varieties that produced a small number of nodules, all nodules (or most of them) were active.

Table 8. *Development of the nodulation apparatus of green bean varieties (2020-2022) (X±SD)*

Variety	Number of nodules, pcs./plant		Mass of nodules, g/plant	
	total	active	total	active
Paloma	14.0±4.9	7.0±4.2	0.18±0.05	0.09±0.04
Frouidor	15.7±5.7	8.0±5.0	0.20±0.07	0.09±0.02
Purpurova Koroleva	7.7±2.1	4.3±1.9	0.12±0.02	0.08±0.01
Laura st	12.0±4.1	5.7±3.1	0.16±0.05	0.09±0.02
Zorenka	12.7±4.5	6.7±3.8	0.12±0.03	0.05±0.01
Casablanca	16.3±6.5	8.0±5.0	0.20±0.08	0.08±0.01
Xmed	13.06	6.61	0.16	0.08
σ_G^2	7.83	5.26	0.001	0.0002
σ_F^2	39.44	22.72	0.005	0.0008
σ_A^2	31.61	17.46	0.004	0.0007
CVG, %	21.43	34.69	19.25	16.11
CVF, %	48.10	72.10	43.26	36.55
CVA, %	43.06	63.20	38.74	32.81
CVG/CVA	0.50	0.55	0.50	0.49

Note: ** – st – standard*
Source: *obtained as a result of author's research*

One of the qualitative indicators of the symbiotic apparatus is the content of legoglobin in nodules. The activity of nitrogen fixation depends more on the content and concentration of legoglobin in the nodules than on their amount. Therefore, the study of the influence of varietal features of legoglobin accumulation is of high practical interest. A high concentration of legoglobin was noted in nodules of high weight – in the varieties Purpurova Koroleva, Laura, and Zorenka – 48.3-60.6 mg/g. The main reserve for increasing the yield of legumes is the scientifically based use of the nutritional potential of the soil, environmental conditions, and new varieties. It is known that at least half of the yield growth is achieved through the use of fertilisers. At the same time, biological nitrogen is an essential source of nutrition. As a result of research, it was revealed that the highest activity of the symbiotic potential was found in Paloma varieties – 3.3 thousand kg·days/ha, while the amount of fixed nitrogen was 51.5 kg/ha; Fruidor – 3.7 thousand kg·days/ha. and 54.6 kg/ha of fixed nitrogen; and Casablanca – 4.2 thousand kg·day/ha and 60.9 kg/ha of fixed nitrogen, respectively (Table 9).

Table 9. *Activity of the symbiotic apparatus of green bean varieties (2020-2022) (X±SD)*

Variety	Legoglobin content, mg/g	Active symbiotic potential, thous. kg×day/ha	Amount of fixed nitrogen, kg/ha
Paloma	44.5±3.7	3.3±0.8	51.5±19.1
Frouidor	43.9±4.7	3.7±1.0	54.6±24.4
Purpurova Koroleva	48.3±19.6	2.2±0.2	37.9±7.0
Laura st	51.9±12.7	3.1±0.7	50.0±16.2
Zorenka	60.6±9.7	2.6±0.3	36.6±10.5
Casablanca	40.6±5.2	4.2±0.9	60.0±25.9
Xmed	48.3	3.2	48.5
σ_G^2	38.93	0.17	114.06
σ_F^2	198.53	1.09	528.79
σ_A^2	159.59	0.93	414.73
CVG, %	12.92	12.88	22.05
CVF, %	29.17	33.14	47.47
CVA, %	26.15	30.53	42.04
CVG/CVA	0.49	0.42	0.52

Note: ** – st – standard*
Source: *obtained as a result of author's research*

Like all previously analysed indicators, the activity of the symbiotic apparatus of green beans to a greater extent depended on the conditions in which the phenotype was formed – CVA=26.15 – 42.04%, rather than on varietal characteristics – CVG=12.88 – 22.05%, which is explained by the low ratio of CVG/CVA=0.42-0.52.

The obtained data on the indicator "height of attachment of the lower bean" (10-18 cm) coincide with the data given in the paper by Ovcharuk *et al.* (2021) – 8.2-16.8 cm and indicates the suitability of green bean varieties for mechanised harvesting in the technical ripeness phase. However, according to the indicator "the number of beans per plant, pcs." data provided by Ovcharuk *et al.* (2021) significantly predominate.

The findings of this study show a significantly lower yield of green bean pods compared to the data obtained by Vitanov *et al.* (2019), where the yield of green beans at a single harvest was 12.6-14.3 t/ha, and by Habtie *et al.* (2021) – 11.5-19.7 t/ha. In this study, a close level of yield was achieved only in the Zorenka variety – 12.7 t/ha. Analysing the indicators of individual productivity of green bean varieties, it can be seen that the results differ significantly from the results obtained by Hema and Rana (2020) in subtropical conditions. Thus, in terms of green bean yield, the studied varieties were less productive than those indicated by Hema and Rana (2020) – 18.3-49.9 t/ha; in terms of the number of beans on the plant, the results were similar – 9.66-21.10 pcs./plant, in our studies – 5-18 pcs./plant. However, in terms of the weight of beans from one plant, the data were low – 9.3-59.7 g/plant, while data noted by Hema and Rana (2020) – 91.68-249.92, which shows a strong differentiation of varieties in terms of productivity and a significant dependence on growing weather conditions.

In the author's studies, the yield of green bean seeds was 0.47-2.89 t/ha, as noted by Garbovska (2019), the yield of green bean seeds was obtained at the level of 1.6-2.4 t/ha, which is significantly higher than in this study, and these results also coincide with the results of Ovcharuk *et al.* (2021). This phenomenon is explained by higher air temperature and lower precipitation and relative humidity in the conditions of author's research, which significantly affects the level of tying and abortivity of bean fruits, which affects the yield.

In this study, the protein content was in the range of 11.33-17.13%, while in the results of Aquino-Bolaños *et al.* (2021), this indicator was between 3.3 and 9.6%. Aquino-Bolaños *et al.* (2021) report the sugar content of 4.86-12.5%, while the present study found significantly less sugar accumulation (in the range of 2.00-2.60%).

The development of the nodulation apparatus also differed significantly from the results published by Hema & Rana (2020). Thus, in this study, the number of nodules was 7.7-16.3 pcs/plant with a total weight of 0.12 to 0.20 g/plant, whereas in the results of Hema & Rana (2020), their number was 7.78-14.59 pcs./plant, weighing 0.075-0.150 g. The comparison of the findings with the results of other researchers showed a significant differentiation of varieties by morphological and economic characteristics, which is explained by genetic differences and soil and climatic conditions.

CONCLUSIONS

The results confirm the advantages of green beans as a dietary product with a high protein content in the technical ripeness phase – Purpurova Koroleva, Paloma, Zorenka, and Casablanca; Purpurova Koroleva and Zorenka – in the biological ripeness phase of the grain. The most valuable in terms of caloric content were green beans of the varieties Fruidor, Purpurova Koroleva, and Laura st – 113.92-137.10 kcal per 100 g of raw weight.

Varieties with the shortest period before the onset of technical ripeness are identified – Purpurova Koroleva, Zorenka, and Casablanca (54-55 days). Evaluating varieties by growth indicators, it was found that the leaf area of crops is the most variable indicator (CV=13-25% depending on the variety), and plant height is the most stable indicator (CV=4-8%). Varieties with a high attachment of the lower bean – 13-16 cm (Zorenka, Paloma and Laura) are also identified, which characterises them as suitable for mechanised harvesting. Varieties with compact, dense bushes that are suitable for repeated harvesting were found – Fruidor, Laura, and Casablanca. As a result of statistical data processing, it was found that plant growth indicators are more dependent on environmental conditions (CVA=10.4-35.8%) than on the genetic component (CVG=4.5-15.6%). According to the weight of green beans per plant, the varieties Zorenka and Casablanca were distinguished, which were characterised by a large weight and alignment of beans.

Assessment of the adaptability and stability of green bean varieties allows identifying varieties that belong to the intensive type. According to the results of research, varieties that are able to successfully adapt to limiting and stressful factors in Forest-Steppe conditions have been identified. Thus, in the conditions of using intensive technologies, it is advisable to grow varieties Paloma, Laura, Zorenka, and Casablanca, which had a ratio of indicators $bi>1$, $\sigma^2 d>0$ – that is, they have better results under favourable growing conditions and were characterised by broad agro-ecological adaptability and belong to intensive varieties on the basis of "green bean yield".

From the data obtained, it can be seen that the yield depends on the number of beans per plant. The number of beans per plant was more dependent on environmental conditions than on varietal characteristics, and the same trend was observed in terms of seed weight per plant and bean and seed yields.

In the direction of nitrogen fixation in production or as a source of a trait in the breeding process, it is necessary to use the varieties Fruidor and Casablanca, in which the level of biologically fixed nitrogen is 54.6 and 60.0 kg/ha. As a result of an ecological study of green bean varieties, it was found that the conditions of the Ukrainian Forest-Steppe are suitable for obtaining high-quality raw materials for processing and seed production. Further research prospects consist in zoning the varieties under study in other zones of Ukraine and investigating the elements of seed production.

ACKNOWLEDGEMENTS

The team of authors expresses their gratitude to the staff of the mass analysis laboratory of the Uman National University of Horticulture for their assistance in research.

CONFLICT OF INTEREST

The authors state that there is no conflict of interest regarding the publication of this paper.

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Агробіологічна оцінка сортів квасолі спаржевої за адаптивністю, продуктивністю та азотфіксацією

Вячеслав Васильович Яценко
Доктор філософії, старший викладач
Уманський національний університет садівництва
20301, вул. Інститутська, 1, м. Умань, Україна
https://orcid.org/0000-0003-2989-0564

Сергій Петрович Полторецький
Доктор сільськогосподарських наук, професор
Уманський національний університет садівництва
20301, вул. Інститутська, 1, м. Умань, Україна
https://orcid.org/0000-0003-3334-0880

Наталія Василівна Яценко
Доктор сільськогосподарських наук, доцент
Уманський національний університет садівництва
20301, вул. Інститутська, 1, м. Умань, Україна
https://orcid.org/0000-0003-3752-314X

Наталія Миколаївна Полторецька
Кандидат сільськогосподарських наук, доцент
Уманський національний університет садівництва
20301, вул. Інститутська, 1, м. Умань, Україна
https://orcid.org/0000-0001-9879-1872

Олександр Васильович Мазур
Кандидат сільськогосподарських наук, доцент
Вінницький національний аграрний університет
21008, вул. Сонячна, 3, м. Вінниця, Україна
https://orcid.org/0000-0002-2237-5116

Анотація. Квасолю необхідно вивчати як екологічний об'єкт, за допомогою якого можна поповнити запаси сполук азоту в ґрунті та підвищити його біологічну активність. За мету ставилося провести науково обґрунтоване районування сортів та оцінити їх адаптивно-продуктивний потенціал за показниками продуктивносі та азотфіксації. Дослідження проводили в умовах навчально-виробничого відділу Уманського національного університету садівництва впродовж 2020-2022 рр., використовували шість сортів, поширених у виробництві. Для вивчення параметрів адаптивної мінливості використано стандартні методи генетико-статистичного аналізу. Дослідження фенологічних змін показало, що залежно від сорту до настання технічної стиглості проходить від 54 до 67 діб, а варіювання даної ознаки складає 8 %. Найкоротшим періодом до збору зелених бобів характеризувалися сорти Зоренька і Касабланка. Варіювання періоду вегетації до настання біологічної стиглості було у межах 90 – 108 діб (CV=6 %). За показником прикріплення нижнього боба виявлено придатні сорти до механізованого збору врожаю – Зоренька і Касабланка. Аналізуючи параметри адаптивності ознак «маса бобів» та «врожайність» виявлено стабільний сорт – Фруідор та високопродуктивні сорти інтенсивного типу Палома, Лаура, Зоренька і Касабланка. Найбільш врожайним був сорт Зоренкьа – 12,7 т/га, а найменш врожайним – Фруідор – 1,9 т/га. За врожайністю насіння виділилися сорти Пурпурова королева, Зоренька та Касабланка врожайність яких була на рівні 2,22-2,89 т/га, що більше від стандарту на 30,8-70,6 %. Аналізуючи залежність параметрів росту і розвитку рослин квасолі спаржевої, видно, що дані ознаки в більшій мірі залежать від умов (CVA, %) у яких вони формувалися, аніж від генотипової складової (CVG, %). Отримані результати надають корисну інформацію щодо товарної й насіннєвої, продуктивності та азотфіксуючої здатності для впровадження у промислове виробництво або подальшої селекційної практики і доводять, що сорти квасолі спаржевої придатні як для отримання овочевої продукції, так і для якісного насіння, а також для біологізації виробництва шляхом використання біологічно фіксованого азоту

Ключові слова: *Phaseolus vulgaris*; фіксація азоту; харчова цінність; продуктивність; протеїн; розчинні цукри

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 26(7), 95-105

UDC 519.233: 635.7 (477.7)
DOI: 10.48077/scihor7.2023.95

Modelling *Salvia sclarea* L. yields depending on plants spacing, mineral fertilisers and depth of ploughing in the irrigated conditions of cold Steppe zone

Victor Chaban
Doctor of Agricultural Sciences, Associate Professor
Kherson State Maritime Academy
73000, 20 Ushakova Str., Kherson, Ukraine
https://orcid.org/0000-0002-4353-4374
Pavlo Lykhovyd*
PhD in Agricultural Sciences
Institute of Climate-Smart Agriculture of NAAS
67667, 24 Mayatska doroha Str., Khlibodarske vill., Ukraine
https://orcid.org/0000-0002-0314-7644
Sergiy Lavrenko
PhD in Agricultural Sciences, Associate Professor
Kherson State Agrarian and Economic University
73006, 23 Stritenska Str., Kherson, Ukraine
https://orcid.org/0000-0003-3491-1438

Article's History:
Received: 2.05.2023
Revised: 26.06.2023
Accepted: 12.07.2023

Abstract. Ukraine has favourable natural conditions for the cultivation of medicinal and aromatic plants, but there is a lack of scientific knowledge and practical guidelines for their cultivation. Clary sage is a valuable and prospective crop for the South of Ukraine and deserves special attention. This study is aimed to investigate theoretical mechanisms of clary sage productivity formation on the irrigated lands of the Southern Ukraine. The experimental basis for the study is the data on crop inflorescence yields, collected during field investigation of clary sage cultivation technology in the drip-irrigated lands of the Kherson Oblast during 2013-2018. Theoretical study on the yield formation depending on the cultivation technology elements was performed through rank correlation and heteroscedasticity analyses, while the mathematical model for the crop yield prediction was developed using multiple regression. As a result, the null hypothesis about the influence of the factors studied on crop yields was denied according to the Breusch-Pagan and Glejser tests, although the results of the analysis of variances revealed no significant effect of the depth of the plough and the spacing of the crop on the yields. Rank correlation analysis revealed that the highest influence on crop yield is attributed to phosphorus fertilisers. In addition, information on the influence of each agrotechnological factor on the yield of clary sage was determined, namely: 1 kg of nitrogen fertilisers applied per ha reduces the yield by 6.34 kg; 1 kg

Suggested Citation:
Chaban, V., Lykhovyd, P., & Lavrenko, S. (2023). Modelling *Salvia sclarea* L. yields depending on plants spacing, mineral fertilisers and depth of ploughing in the irrigated conditions of cold Steppe zone. *Scientific Horizons*, 26(7), 95-105. doi: 10.48077/scihor7.2023.95.

*Corresponding author

of phosphorus fertilisers applied per ha increases the yield by 156.44 kg; 1 extra cm of row spacing reduces the yield by 3.33 kg; 1 cm deeper ploughing improves the yield by 56.56 kg. The model has moderate fitting quality (correlation coefficient 0.5885) and reasonably good yield prediction accuracy (mean absolute percentage error 24.12%). The study has no analogues in Ukraine or in the world and provides novel theoretical and practical insights on the formation of clary sage productivity in the cold Steppe zone

Keywords: variance analysis; drip irrigation; medicinal plants; multiple regression analysis; rank correlation; South of Ukraine; yield prediction

INTRODUCTION

Crop yields modelling and prediction is an important task of modern agricultural science. Yield predictions and forecasts are necessary for rational adjustment of the agrotechnological aspects of crops cultivation, as well as economic planning, agricultural market policy formation, making decisions on food export and import, etc. (Lykhovyd *et al.*, 2023). Currently, various crop yield prediction models are deeply integrated in decision support systems; for example, DSSAT, used by agricultural practitioners and stakeholders to improve water, land, soil, and crop management through empirical modelling of some major crop responses to changing environmental and agrotechnological parameters, entered the system.

Empirical and statistical crop modelling is impossible without previous in-field or *in vitro* studies. Therefore, field research is the basis for mathematical and theoretical work. Modelling the yields of medicinal plants is not widespread, although it is important to better understand the processes of their productivity formation. As far as Ukraine possesses favourable soil and climate conditions for cultivation of most medicinal and aromatic plants, it is necessary both to develop regional cultivation technologies and deepen theoretical knowledge on the crops' productivity formation.

Clary sage is a valuable medicinal plant, which is in high demand on the global market due to the unique content of volatile compounds in its raw material (Acimovic *et al.*, 2022). The essential oil of this crop is used in the pharmaceutical and perfumery industries. Currently, the main producers of the raw material of clary sage are France, Bulgaria, and Hungary (Fopa-Fomeju *et al.*, 2020). To improve the production of clary sage in Ukraine, it is important to develop regional cultivation technology and provide theoretical substantiation of its elements.

Clary sage cultivation is not sufficiently investigated in Ukraine and abroad. Besides, in-field studies on clary sage productivity are limited in the studied factors. For example, Elgaml *et al.* (2022) considered the effects of different irrigation modes (100% and 50% ETo) on the yield, essential oil output, and physiological aspects of clary sage growth and development in Egypt. Verma *et al.* (2023) studied the effects of different temperature regimes on crop emergence and germination rates, which is quite a specific and narrow subject. Koul *et al.* (2017) established some patterns of clary sage reaction to different altitudes and climate patterns (subtropical or temperate climate). At the same time, some scientific groups studied clary sage from the phytoremediation standpoint, for example, Dobrikova *et al.* (2021) proved that the crop is prospective for sanitation of Zn-polluted lands.

Most scientific research on the cultivation technology and productivity assessment describe the results, devoted to the related species *Salvia officinalis* L., or common sage. For example, Ukrainian researchers Panfilova & Fedorchuk (2022) investigated the efficiency of biological preparations and mineral fertilisers application on the crops of *Salvia officinalis* L. under the conditions of the Southern Steppe zone of Ukraine, while their colleagues Svydenko *et al.* (2022) performed robust investigations on the best genotypes for sage cultivation in the above-mentioned agro-climatic zone. Kotyuk *et al.* (2022) conducted one of the most prospective and valuable studies on the cultivation of *Salvia sclarea* L. to establish the possibilities of the introduction and productivity of clary sage in the conditions of the Central Polissia zone. As a result, researchers found that the crop is prospective and deserves the attention of Ukrainian farmers. The main drawback of the quoted studies is absence of theoretical mathematical substantiation of the crop productivity depending on the environmental, genetic, and agrotechnological factors.

The goals of current study are: 1) to determine the crop's productivity depending on tillage, spacing, and fertilisation options; 2) to derive theoretical mathematical model of clary sage yield formation in the drip-irrigated conditions of the South of Ukraine depending on selected agrotechnological factors using multiple regression analysis.

MATERIALS AND METHODS

The study, described in the paper, was performed in two separate stages. The first stage included carrying out field experiments on the influence of agrotechnology on the yields of clary sage. The second stage included statistical processing of the data collected in field trials and drawing conclusions about crop yield modelling and the influence of each agrotechnological factor on the yield of clary sage.

Stage 1

The experimental study on the influence of cultivation technology on the yields of clary sage inflorescences was carried out in the experimental field, located on

the territory of the 'Dodola' agricultural farm (Beryslav district, Kherson Oblast, Ukraine). The study was conducted during 2013-2018 and included the estimation of such agrotechnological elements as follows:

- Factor A – mineral fertiliser application rates – N_0 P_0 (0 kg ha^{-1} in total), N_{60} P_{30} (90 kg ha^{-1} in total), N_{60} P_{60} (120 kg ha^{-1} in total), N_{60} P_{90} (150 kg ha^{-1} in total);
- Factor B – spacing of the plants (the distance between the rows) – 45 cm, 70 cm;
- Factor C – depth of ploughing – 20-22 cm, 28-30 cm.

The study was performed in four replications using split plot randomised design method. The average area of the sown plot was 105 m^2, the accounting area was 50 m^2.

The soil of the experimental field was represented by dark-chestnut, slightly saline, middle-loamy soil with the bulk density of 1.43 g cm^{-3}, field water capacity of 21.5%, wilting point of 9.1%, humus content of 2.18%, available nitrogen, phosphorus, and potassium content of 12.5-24.8, 16.8-39.5, 325-380 mg kg^{-1}, respectively. Weather conditions in the study period were typical for the climatic zone of the southern steppe of Ukraine.

Clary sage of Taihan variety was used in the trials. The predecessor was winter wheat. In the pre-ploughing period, double harrowing was conducted to the depth of 6-8 cm. Mouldboard ploughing was conducted in late autumn strictly with accordance to the study design. Mineral fertilisers were applied in the form of super phosphate and ammonium nitrate as foreseen by the scheme of the experiment. Clary sage was sown after pre-sowing soil tillage using standard sowing machine with accordance to plant spacing, stipulated by the study design. Plant care included drip irrigation, which was carried out according to weather conditions and available soil moisture (2-4 waterings were generally carried out per growing season) to maintain it at the level of 70-75% of the field water capacity in the layer 0-50 cm, and cultivating the space between the crop rows to a depth of 6-8 cm. Harvesting of clary sage inflorescences was conducted manually in the first year of the crop use, and with the harvesting machine "Ros-2" in the second-fourth years of the crop use, with immediate weighing of the harvest. In total, clary sage was harvested four times (four years of crop use). The cumulative yield of the crop was calculated as the sum of the yields for each year. The yields were statistically analysed using standard three-way analyses of variance (ANOVA) procedure, explained by Schmuller (2021), within the framework of BioStat v.7 to determine the significance of the differences between the variants by the values of the Fisher's least significant difference at $p<0.05$ (LSD_{05}). Standard deviations in crop yields were calculated according to Shi *et al.* (2020).

Stage 2

Statistical analysis was performed using the standard procedure for linear multiple regression and rank correlation in BioStat v.7 software (Fieller *et al.*, 1957; Uyanık & Güler, 2013). The strength of the relationship between the yields of clary sage and the agrotechnological factors studied was established using the classification proposed by Evans (1996). The influence of the elements of the cultivation technology on crop productivity was also assessed by the values of the regression coefficients. The quality of the fitting of the model for the prediction of clary sage yield was evaluated by the Pearson correlation coefficient values, while the accuracy was judged by the mean absolute percentage error (MAPE) using the guidelines of Blasco *et al.* (2013). The calculations of MAPE were performed according to De Myttenaere *et al.* (2016). Heteroscedasticity of the data was also checked by Breusch-Pagan test (Breusch & Pagan, 1979) and Glejser test (Glejser, 1969) to accept or deny the null hypothesis for the relationship between the cultivation technology options and clary sage yields. The visual approximation of the multiple regression model was performed using the Microsoft Excel 365 graphical toolkit to depict the fitting quality of the developed equation.

RESULTS AND DISCUSSION

The results of the first stage of the study revealed some key features of clary sage productivity formation under the impact of agrotechnological factors, namely, that the yield of clary sage inflorescences is not statistically significant effected by ploughing or spacing (Table 1 and Table 2). The highest yield was recorded in the variant of ploughing on 28-30 cm, plant spacing of 45 cm, and mineral fertiliser applications rates of $N_{60}P_{90}$. The lowest productivity was recorded when the crop was cultivated in ploughing 20-22 cm with a spacing of 45 cm and no fertilisers were applied. Significant effect on the yield is attributed to the total dose of mineral fertilisers applied, where the pairs of 0 vs 120, 0 vs 150, and 90 vs 150 are significantly different in productivity. Thus, it was established that the depth of tillage and the spacing of the crops are not of great importance for the formation of the productivity of clary sage under irrigated conditions. Moreover, Giannoulis *et al.* (2021) proved that plant density had negative effect on the yields of a related species *Salvia officinalis* L., while their results support the claim of better crop productivity under mineral fertilisation. Katar *et al.* (2022) also supports the statement that salvia productivity benefits from fertiliser application; however, essential oil yields could be decreased at higher rates of mineral nitrogen. There is a gap in scientific literature about the effects of tillage on the productivity of clary sage, therefore, current study provides a breakthrough in this subject.

As the cumulative yields of the clary sage inflorescences for four years of crop use were calculated and generalised with correspondence to the options of cultivation technology and their combinations, Table 3 was created to represent the inputs, used to perform the modelling and statistical investigation of the yields. There were 64 data pairs in total.

Table 1. *Yields of clary sage inflorescences depending on the depth of ploughing, crop spacing, and fertilisers application rates (average for four years of the crop use)*

Factor A (total rates of NP fertiliser applied, kg×ha^{-1})	Factor B (crop spacing, cm)	Factor C (depth of ploughing, cm)	Clary sage inflorescences yield, t×ha^{-1}±standard deviation
0	45	20-22	19.07±2.57
			17.74±2.40
			14.28±1.93
	70		12.81±1.74
			19.16±2.58
			18.40±2.49
			14.28±1.94
			14.25±1.93
	45	28-30	20.08±3.83
			17.72±2.64
			14.31±2.52
	70		14.46±2.13
			21.06±3.90
			17.98±2.77
			14.94±2.61
			14.22±2.08
90	45	20-22	28.08±5.08
			19.35±3.95
			18.59±2.68
	70		15.21±2.10
			28.56±5.32
			20.36±3.98
			19.13±2.82
			15.69±2.22
	45	28-30	28.56±6.15
			20.07±4.59
			19.52±3.22
	70		14.55±2.34
			25.67±5.89
			21.01±4.19
			20.30±3.50
			14.78±2.40
120	45	20-22	37.93±2.73
			29.11±2.37
			19.57±1.93
	70		15.77±1.96
			38.84±2.90
			29.24±2.43
			20.61±1.99
			16.33±1.93
	45	28-30	40.52±3.85
			29.55±2.75
			23.12±2.66
			15.91±1.97
120	70	28-30	30.21±3.44
			29.98±2.86
			24.16±2.77
			16.67±1.97

Table 1, Continued

Factor A (total rates of NP fertiliser applied, kg×ha^{-1})	Factor B (crop spacing, cm)	Factor C (depth of ploughing, cm)	Clary sage inflorescences yield, t×ha^{-1}±standard deviation
150	45	20-22	45.51±5.52
			33.82±3.96
			23.55±3.15
	70		17.46±2.16
			42.47±3.86
			30.58±4.08
			24.97±3.30
			17.70±2.25
	45	28-30	46.29±6.28
			33.74±4.57
			23.68±3.22
	70		17.06±2.32
			45.24±6.14
			32.34±4.38
			27.77±3.78
			17.43±2.35

Source: *compiled by the authors*

Table 2. *Average yield of clary sage inflorescences by the studied agrotechnological factors, and the results of three-way analysis of variance*

Factor A gradations	Yield, t ha^{-1}	Factor B gradations	Yield, t ha^{-1}	Factor C gradations	Yield, t ha^{-1}
0	16.55	45	23.34	20-22	23.08
90	20.59	70	23.26	28-30	23.53
120	26.10	LSD_{05}	0.75, not significant	LSD_{05}	4.06, not significant
150	29.98				
LSD_{05}	8.43, significant				

Source: *compiled by the authors*

Table 3. *Inputs for the modelling and statistical analysis of cumulative clary sage yields*

Fertilisers, kg ha^{-1}		Spacing, cm	Ploughing depth, cm	Cumulative clary sage yield
Nitrogen (N)	Phosphorus (P)			
0	0	45	21	19.07
0	0	45	21	17.74
0	0	45	21	14.28
0	0	45	21	12.81
0	0	70	21	19.16
0	0	70	21	18.40
0	0	70	21	14.28
0	0	70	21	14.25
60	30	45	21	28.08
60	30	45	21	19.35
60	30	45	21	18.59
60	30	45	21	15.21
60	30	70	21	28.56
60	30	70	21	20.36
60	30	70	21	19.13
60	30	70	21	15.69
60	60	45	21	37.93
60	60	45	21	29.11

Table 3, Continued

Fertilisers, kg ha^{-1}		Spacing, cm	Ploughing depth, cm	Cumulative clary sage yield
Nitrogen (N)	Phosphorus (P)			
60	60	45	21	19.57
60	60	45	21	15.77
60	60	70	21	38.84
60	60	70	21	29.24
60	60	70	21	20.61
60	60	70	21	16.33
60	90	45	21	45.51
60	90	45	21	33.82
60	90	45	21	23.55
60	90	45	21	17.46
60	90	70	21	42.47
60	90	70	21	30.58
60	90	70	21	24.97
60	90	70	21	17.70
0	0	45	29	20.08
0	0	45	29	17.72
0	0	45	29	14.31
0	0	45	29	14.46
0	0	70	29	21.06
0	0	70	29	17.98
0	0	70	29	14.94
0	0	70	29	14.22
60	30	45	29	28.56
60	30	45	29	20.07
60	30	45	29	19.52
60	30	45	29	14.55
60	30	70	29	25.67
60	30	70	29	21.01
60	30	70	29	20.30
60	30	70	29	14.78
60	60	45	29	40.52
60	60	45	29	29.55
60	60	45	29	23.12
60	60	45	29	15.91
60	60	70	29	30.21
60	60	70	29	29.98
60	60	70	29	24.16
60	60	70	29	16.67
60	90	45	29	46.29
60	90	45	29	33.74
60	90	45	29	23.68
60	90	45	29	17.06
60	90	70	29	45.24
60	90	70	29	32.34
60	90	70	29	27.77
60	90	70	29	17.43

Source: *compiled by the authors*

First, data were used to determine the strength of the relationship between each agrotechnological option studied and the yield of clary sage by rank correlation analysis. The correlation coefficients of Spearman (ρ), Kendall (τ), Pearson (r), Goodman and Kruskal (γ) were calculated and presented in Table 4.

Table 4. *Rank correlations for the relationship between the elements of cultivation technology and the yields of clary sage*

Cultivation technology element	Correlation coefficients			
	Spearman (ρ)	Kendall (τ)	Goodman and Kruskal (γ)	Pearson (r)
Nitrogen (N)	0.52	0.43	0.70	0.45
Phosphorus (P)	0.59	0.48	0.55	0.59
Spacing, cm	0.03	0.03	0.04	0.01
Ploughing depth, cm	0.04	0.04	0.05	0.03

Source: *prepared on the basis of the authors' genuine research*

According to the results of the rank correlation analysis, the strongest relationship (and the greatest impact on clary sage yields) is attributed to phosphorus fertilisers, while the slightest relationship (almost absent) is attributed to the spacing of the plants and the depth of ploughing. Therefore, fertilisation has a decisive role in the determination of drip-irrigated clary sage yields. The results of Breusch-Pagan and Glejser tests are provided in Table 5. The tests confirm that the null hypothesis is denied, so it could be assured that the factors studied had a statistically significant influence on the yields of the studied crop.

Table 5. *Results of heteroskedasticity tests for the input data set*

Statistical index	Value
Breusch-Pagan test	
Statistics of the test	2.0720
P-value	0.0004
Degrees of freedom	4
Critical value	9.4877
Null hypothesis	Denied
Glejser test	
Statistics of the test	22.1300
P-value	0.0002
Degrees of freedom	4
Critical value	9.4877
Null hypothesis	Denied

Source: *compiled by the authors*

Further, linear multiple regression analysis was performed. The statistics for the analysis and the developed model are provided in Table 6. It is evident that the model has moderate fitting quality (according to the value of correlation coefficient), and reasonable prediction accuracy (according to the value of MAPE, which falls within the range 20-50%) with a greater inclination to good accuracy (requires MAPE within 10-20%).

Table 6. *Regression statistics and the model's equation for the prediction of clary sage yields depending on mineral fertilisers rates, spacing, and depth of ploughing*

Statistical parameter	Value
Correlation coefficient	0.5885
Coefficient of determination	0.3463
Adjusted coefficient of determination	0.3020
Predicted coefficient of determination	0.2383
Mean absolute percentage error	24.12%
Equation	$15.325-6.3403\times10^{-3}\times N+1.5644\times10^{-1}\times P-3.3250\times10^{-3}\times S+5.6563\times10^{-2}\times D$

Note: *N – the dose of Nitrogen fertilisers applied, kg×ha^{-1}; P – the dose of Phosphorus fertilisers applied, kg×ha^{-1}; S – spacing, cm; D – depth of ploughing, cm*

Source: *compiled by the authors*

According to the modelling results and obtained values of regression coefficients for each element of cultivation technology, it is possible to state that every kg of Nitrogen fertilisers applied per ha reduces clary sage yields by 6.3403 kg, every kg of Phosphorus fertilisers applied per ha increases clary sage yields by 156.44 kg, every additional cm of between row spacing reduces the yields by 3.325 kg, and every cm of additional depth of ploughing above 22 cm improves the crop yield by 56.563 kg. Therefore, it is quite surprising that Nitrogen fertilisers manifested their action not in supposed enhancement of clary sage yields but provided weak inhibitory activity. It is also proved that greater spacing, meaning lower plant density, results in the yield losses. Deep ploughing is favourable for obtaining higher yields of clary sage in the south of Ukraine; therefore, it is reasonable to spend additional labour, time, and material resources to provide deeper loosening of the soil under clary sage. Visual approximation and fitting quality assessment are provided in Figure 1.

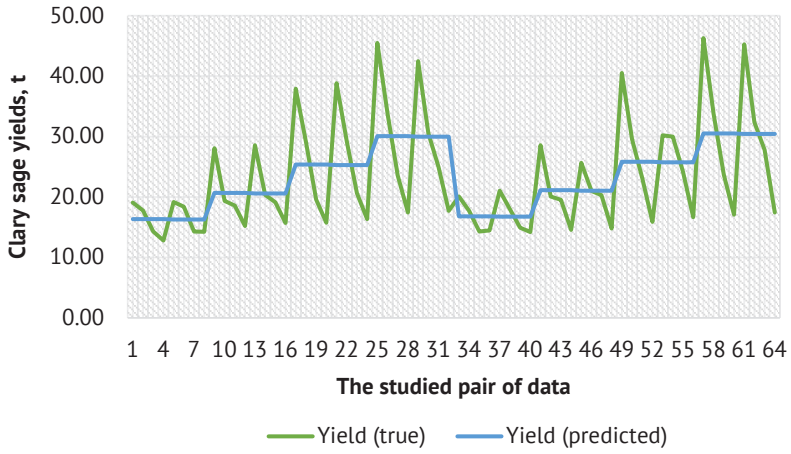

Figure 1. *Visual approximation of clary sage productivity model*
Source: *compiled by the authors*

Current study has no analogues in Ukraine, and it is the first to provide deep mathematical analysis of clary sage productivity formation under the drip-irrigated conditions of the South of Ukraine, as well as to provide the mathematical equation for yield prediction of this crop, though the studies on cultivation technology and biological features of the crop were performed by Ukrainian researchers (Yurchak & Pobirchenko, 1997). For example, Knyazyuk *et al.* (2018) conducted the investigation of clary sage productivity depending on the terms of sowing and plant spacing and obtained the results, which are in agreement with the current study, that the highest yields of the crop could be harvested under a spacing of 45 cm. But there was no deep mathematical analysis of the formation of crop productivity in the research papers quoted above. It was also impossible to find any similar work in foreign sources, as most studies devoted to clary sage productivity investigation are limited to field work and focused on the interpretation of the crop productivity with no complicated statistical apparatus engaged (while correlation coefficient and error calculations are common for almost every work), and provide no deep statistical analysis, e.g., as the studies by Singh *et al.* (2008), Verma *et al.* (2010), Fathi *et al.* (2012), Yaseen *et al.* (2014), and other foreign researchers. Therefore, the current study presents novel insights for global scientific knowledge on the formation of clary sage yields under the influence of some agrotechnological factors, such as mineral fertilisation, plough depth and plant spacing. The results are of a special value for the South of Ukraine and could be extrapolated to the areas with similar soil-climatic conditions with accordance to modern climate classification – namely, BSk zone, the cold Steppe climate (Beck *et al.*, 2018).

To sum up the results of the current study, it is required to note that it has some limitations, mainly with respect to the number of agrotechnological factors studied, as many elements of cultivation technology remained out of sight in this research. Furthermore, the results about the low efficiency of the tillage depth in the increase in yield could be put under doubt if the crop is grown in rainfed conditions, as it is believed that irrigation can lead to the nullification of positive effects from deep ploughing (Lavrenko *et al.*, 2021). At the same time, the developed model for clary sage productivity prediction has no analogues in Ukraine and in the world, and it is the first one to implement mathematical methods for better understanding of the crop yield formation under various cultivation technology practices.

CONCLUSIONS

Clary sage's productivity in the drip-irrigated conditions of the South of Ukraine mainly depends on fertilisation, as the depth of ploughing and plants spacing play neglectable role and provide yield increase, which is not

statistically significant according to the ANOVA results. The best yield capacity (46.29±6.28 t/ha^{-1}) is attributed to the variant with the ploughing 28-30 cm, the spacing of the plants 45 cm, and the rates of application of mineral fertilisers $N_{60}P_{90}$. Statistical analysis testifies about the highest importance of phosphorus fertilisers (Pearson's correlation coefficient is 0.59) in achieving the best yield quantity, while plant spacing and ploughing depth play a secondary role in clary sage productivity.

As a result of our study, a mathematical equation for the prediction of the yield of clary sage inflorescences has been developed based on the rates of mineral fertilisers, the spacing and the depth of ploughing. The model has moderate fitting quality (correlation coefficient is 0.5885) and reasonably good prediction accuracy (mean absolute percentage error is 24.12%), providing novel information on the specifics of the formation of crop productivity under irrigated conditions in the south of Ukraine. Surprisingly, regression analysis revealed that nitrogen fertilisers can slightly decrease yield (per 6.34 kg ha^{-1} for each kg ha^{-1} applied), although it is commonly expected that they improve crop productivity. The results of the study have no analogues in Ukraine or elsewhere and provide valuable scientific information on the cultivation of clary sage in the climatic zone of the soil of BSk.

Further investigations are to be conducted to deepen the obtained theoretical knowledge on clary sage productivity formation, including the factors, which were not embraced in current study. In addition, other mathematical and statistical approaches should be applied to improve the quality of the yielding model.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Моделювання врожайності *Salvia sclarea* L. залежно від ширини міжрядь, мінеральних добрив та глибини оранки в зрошуваних умовах холодного Степу

Віктор Чабан

Доктор сільськогосподарських наук, доцент
Херсонська державна морська академія
73000, вул. Ушакова, 20, м. Херсон, Україна
https://orcid.org/0000-0002-4353-4374

Павло Лиховид

Кандидат сільськогосподарських наук
Інститут кліматично орієнтованого землеробства НААН
67667, вул. Маяцька дорога, 24, с. Хлібодарське, Україна
https://orcid.org/0000-0002-0314-7644

Сергій Лавренко

Кандидат сільськогосподарських наук, доцент
Херсонський державний аграрно-економічний університет
73006, вул. Стрітенська, 23, м. Херсон, Україна
https://orcid.org/0000-0003-3491-1438

Анотація. Україна має сприятливі природні умови для вирощування лікарських та ароматичних рослин, але бракує наукових знань та практичних рекомендацій щодо їх вирощування. Шавлія мускатна є цінною та перспективною культурою для Півдня України і заслуговує на особливу увагу. Метою даної роботи є дослідження теоретичних механізмів формування продуктивності шавлії мускатної на зрошуваних землях Півдня України. Експериментальною базою дослідження є дані про врожайність суцвіть культури, зібрані під час польових досліджень технології вирощування шавлії мускатної на краплинному зрошенні в Херсонській області протягом 2013-2018 рр. Теоретичне дослідження формування врожайності залежно від елементів технології вирощування проводилося за допомогою рангового кореляційного та гетероскедастичного аналізів, а математична модель для прогнозування врожайності розроблялася з використанням множинної регресії. В результаті нульова гіпотеза про вплив досліджуваних факторів на врожайність була спростована за критеріями Бреуша-Пагана та Глейзера, хоча результати дисперсійного аналізу не виявили значущого впливу глибини плуга та ширини міжрядь на врожайність. Аналіз рангової кореляції показав, що найбільший вплив на врожайність мають фосфорні добрива. Крім того, визначено інформацію про вплив кожного агротехнологічного фактора на врожайність шавлії мускатної, а саме 1 кг азотних добрив, внесених на 1 га, зменшує врожайність на 6,34 кг; 1 кг фосфорних добрив, внесених на 1 га, збільшує врожайність на 156,44 кг; 1 додатковий сантиметр ширини міжрядь зменшує врожайність на 3,33 кг; оранка на 1 см глибше підвищує врожайність на 56,56 кг. Модель має помірну якість підгонки (коефіцієнт кореляції 0,5885) і досить хорошу точність прогнозування врожайності (середня абсолютна відсоткова похибка 24,12 %). Дослідження не має аналогів в Україні та світі і дає нові теоретичні та практичні уявлення про формування продуктивності шавлії мускатної в зоні холодного Степу

Ключові слова: дисперсійний аналіз; краплинне зрошення; лікарські рослини; множинний регресійний аналіз; рангова кореляція; Південь України; прогнозування врожайності

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 26(7), 106-117

UDC 635
DOI: 10.48077/scihor7.2023.106

Features of growing garden strawberries in open ground conditions

Ermir Shahini*
Lecturer
Aleksandër Moisiu University of Durrës
2001, 14 Currila Str., Durres, Albania
https://orcid.org/0000-0002-0083-1029
Ajten Berxolli
PhD, Lecturer
Agricultural University of Tirana
1025, Paisi Vodica Str., Tirana, Albania
https://orcid.org/0009-0004-4912-5207
Oleh Kovalenko
Doctor of Agricultural Sciences, Associate Professor
Mykolaiv National Agrarian University
54008, 9 Georgiy Gongadze Str., Mykolaiv, Ukraine
https://orcid.org/0000-0002-2724-3614
Nataliia Markova
PhD in Agricultural Sciences, Associate Professor
Mykolayiv National Agrarian University
54008, 9 Georgiy Gongadze Str., Mykolaiv, Ukraine
https://orcid.org/0000-0001-6169-6978
Yurii Zadorozhnii
Senior Lecturer
Mykolayiv National Agrarian University
54008, 9 Georgiy Gongadze Str., Mykolaiv, Ukraine
https://orcid.org/0000-0003-3499-7753

Article's History:
Received: 25.04.2023
Revised: 20.06.2023
Accepted: 6.07.2023

Abstract. The purpose of this study was to evaluate the effectiveness of strawberry cultivation in the use of PH regulators, synthetic and organic fertilisers, mulching practices, and the use of fungicides, insecticides, and herbicides. The pH of the soil was regulated by applying aluminium sulphate and limestone in the amount of 200 and 900 g per three square metres, respectively. Synthetic preparations with different macro- and microelements, as well as organic compost, were used to test the effect of fertilisers. The growth characteristics of the growing season, including flowering and fruiting indicators, were evaluated. The results showed that a decrease in soil pH has a positive effect on the efficiency of growing the plants under study. The use of

Suggested Citation:
Shahini, E., Berxolli, A., Kovalenko, O., Markova, N., & Zadorozhnii, Yu. (2023). Features of growing garden strawberries in open ground conditions. *Scientific Horizons*, 26(7), 106-117. doi: 10.48077/scihor7.2023.106.

*Corresponding author

fertilisers with a high potassium content increased the growth rate of the growing season, and preparations rich in phosphorus had a positive effect on the characteristics of the flowering period. The use of compost provided an increase in the productivity of strawberries, comparable to the use of synthetic fertilisers. Mulching has been shown to reduce the risk of fungal infections in plants and to increase growth indicators. The use of the herbicide was significantly effective in suppressing the growth of pest plants and improving the growth characteristics of strawberries. It was shown that the use of organic farming methods and reduced concentrations of herbicides and insecticides allows achieving high efficiency of strawberry cultivation

Keywords: growth characteristics; organic farming; synthetic fertilisers; mulching; fruit and berry crops

INTRODUCTION

Garden strawberries are an important crop for many farms, providing a significant source of income for them. It is of particular importance for small entrepreneurs who can cultivate strawberries on a smaller plot of land and at the same time earn a high income. This plant is relatively easy to grow and is suitable for cultivation in various conditions, which makes it a universal crop. Garden strawberries are grown in the open ground or in greenhouses, for which both conventional and organic farming methods are used. Strawberries have a short growing season, which means that farms can harvest multiple crops in one year. This makes this plant attractive for entrepreneurs who are interested in getting maximum profit. Strawberries are also an important crop for the local economy, as they are suitable for sale directly to consumers. This helps support small and medium-sized businesses and creates jobs in the community.

Strawberries are widely used in the food industry to make a variety of products, including jams, jellies, syrups, and pastries. Berries are usually consumed fresh, or frozen, used for preservation, as well as dried and used in the manufacture of ready-to-eat foods. Strawberry flavourings are a popular addition to dairy products such as ice cream, yoghurts, and milkshakes. This plant is of high importance for environmental protection, as it is suitable for use in sustainable farming practices (Romero-Gámez & Suárez-Rey, 2020). In the case of using natural methods of pest and infection control, as well as using cover crops and crop rotation to maintain soil health, farms are able to reduce their negative impact on the environment.

Garden strawberries grow in most soil types, but A. Van Bruggen *et al*. (2016) point out that too sandy soil can lead to drought problems, and heavy clay soils with poor drainage can cause diseases such as late blight. Strawberries grow best in fertile soils with a high content of organic substances. They should be well drained, but at the same time able to retain a constant amount of moisture. According to E.P. Bugawisan (2022), a slightly acidic soil pH is optimal for strawberries.

Fertilisers can be a significant benefit for growing strawberries, as they provide plants with the nutrients they need for growth and fruiting. S. Farjana *et al*. (2023) report that strawberries require balanced fertilisers that contain nitrogen, phosphorus, potassium, and trace elements such as iron, magnesium, and manganese. Organic fertilisers such as compost, manure, or fish emulsion are also used to provide the soil with nutrients. These types of fertilisers are often preferred by organic producers because they are less likely to cause environmental problems and can contribute to soil health over time. However, it is important to use fertilisers correctly and in the right amount, as excessive use of them can lead to environmental problems and even harm the plants themselves. G. Costamagna *et al*. (2020) have shown that too much fertiliser can lead to excessive vegetative growth and impair fruit quality and increase the risk of disease. In addition, excess fertilisers can be washed out into ground water or nearby water bodies, which also leads to environmental problems.

The use of herbicides and insecticides for growing strawberries is a subject of discussion among producers and agricultural experts. A. Monteiro and S. Santos (2022) report that while such compounds can be effective in controlling weeds and pests, they can also have a negative impact on the environment and human health if not used properly. Organic producers can resort to alternative pest and disease control methods, which include crop rotation, the use of sustainable varieties, and practices such as pruning and mulching. These methods can be effective in reducing the pressure of pests and diseases without the use of synthetic chemicals.

The purpose of this study was to evaluate the influence of factors such as soil pH, the use of synthetic and organic fertilisers, various concentrations of herbicides, fungicides, and insecticides, and mulching practices on the growth characteristics of various varieties of garden strawberries.

MATERIALS AND METHODS

The study considers seeds of garden strawberries of the varieties "Regina", "Ruegen", "Alexandria", and "Baron Von Solemacher" of the SeedEra company, Ukraine. The seeds were sown in early spring in closed ground conditions. Before sowing, the seeds were treated with a 1% potassium permanganate solution to protect against infections. Seedlings were grown at 25°C in natural light. After eight weeks, the plants were transferred to the open ground. Strawberry bushes were planted on plots of three square metres at a distance of 30 cm

from each other. Irrigation was carried out once a week, the volume of water for irrigation was 40 litres per plot.

To test the effect of the soil pH indicator on the efficiency of growing garden strawberries, experimental plots were treated with solutions of aluminium sulphate and limestone. Aluminium sulphate was used in the amount of 200 g per site, and limestone materials in the amount of 900 g in terms of CaO per site. A manual pH meter model AZ-8694 (AZ-Instruments, Taiwan) was used to determine the pH. The results obtained were compared with soil that was not treated with chemicals, the pH value of which was 6.5.

Fertilisers of the Verde line by Yochem, Ukraine, were used for testing fertilisers. The effectiveness of using VerdeGrow, VerdeBloom, and VerdeMicro separately, a complex of all three preparations, and the effectiveness of using compost and growing garden strawberries without using fertilisers, was evaluated. VerdeGrow is designed to improve the growth and development of young plants and contains 2% by weight of nitrogen in the form of NO_3 and NH_4^+, 1% phosphorus in the form of P_2O_5, and 6% potassium in the form of K_2O. These macronutrients are most important for balanced plant development. Verdebloom fertiliser is designed to nourish the plant during flowering and fruiting and contains 8% phosphorus in the form of P_2O_5 and 4% potassium in the form of K_2O. VerdeMicro fertiliser is designed to provide plants with the necessary trace elements and contains 5% nitrogen in the form of NO_3 and NH_4^+, 3% potassium in the form of K_2O, and 5% calcium, 0.01% boron, 0.0005% cobalt, 0.01% copper, 0.1% iron, 0.05% manganese, 0.0008% molybdenum, and 0.015% zinc. The number of millilitres of fertiliser concentrate per 40 litres of irrigation water is shown in Table 1.

***Table 1**. Use of fertilisers, ml of concentrate per 40 l of irrigation water*

	Week 1-6	Week 7-14	Week 15-21	Week 22-25
VerdeGrow	8	16	12	4
VerdeMicro	8	12	12	12
VerdeBloom	8	4	12	16

***Source:** developed by the authors*

Trichodermin (Enzim Agro, Ukraine) was used to test the fungicide. The effectiveness of the drug was evaluated when it was applied in the amount of 1, 0.5, and 0.25 ml per site. Abamectin (Syngenta, Switzerland) was used to test the insecticide. The effectiveness of the substance was evaluated when it was applied in the amount of 6, 3, and 1 mg per site. Fluazifop-p-butyl (Syngenta, Switzerland) was used to test the herbicide. The effectiveness of the substance was evaluated when it was applied in the amount of 90, 60, and 30 mg per site. The results were compared with the growth characteristics of strawberry plants without the use of synthetic chemicals when using mulching methods and without it.

To determine the effectiveness of growing plants for each site, such indicators as the average number of whiskers after two weeks of growth, the average number of trifoliate leaves at the time of the first flowering, the number of days before the appearance of the first visible flower buds, the number of days before the ripening of the first berries, the number of flowers on the site for the entire flowering period, and the total weight of fruits from the site were evaluated. To assess the effectiveness of the fungicide and mulching practices, the number of plants affected by diseases was also evaluated. All experiments were performed in three repetitions. The tables show average statistically reliable data.

RESULTS

The application of aluminium sulphate allowed reducing the pH of the soil to an average value of 5.2. When using limestone materials, this indicator increased to 7.1. Data on the influence of soil pH on the growth characteristics of garden strawberry plants of various varieties are shown in Table 2.

The pH value of the soil did not significantly affect the number of whiskers formed by strawberry plants after two weeks of cultivation in open-ground conditions. It is worth noting, however, that for most of the varieties, this characteristic was somewhat less when using limestone materials. Acidification of the soil had a positive effect on the number of triple leaves at the time of the first flowering for the varieties "Regina", "Ruegen", and "Alexandria". An increase in the soil pH value reduced this indicator for the varieties "Ruegen" and "Baron Von Solemacher".

***Table 2**. Influence of the soil pH value on the growth characteristics of garden strawberry plants*

	Variety	Number of whiskers per plant	Number of trifoliate leaves per plant	Days before flowering	Days before the first fruits ripen	Number of flowers from the plot	Fruit weight per plot (g)
pH 6.5	Regina	2.8	5	28.3	62.7	130.3	2.645
	Ruegen	2.7	5.6	30.3	58.7	155.7	2.976
	Alexandria	2.4	4.5	25	53.3	112	2.765

Table 2, Continued

	Variety	Number of whiskers per plant	Number of trifoliate leaves per plant	Days before flowering	Days before the first fruits ripen	Number of flowers from the plot	Fruit weight per plot (g)
pH 6.5	Baron Von Solemacher	3.1	6.1	34	65	137.3	2.988
pH 5.2	Regina	2.7	6.2	26.3	63	158.3	2.875
	Ruegen	2.7	7.1	32	57.7	186.7	3.144
	Alexandria	2.5	5.6	24.7	56.3	147.3	3.072
	Baron Von Solemacher	3	6	32.3	68.3	165.3	3.256
pH 7.1	Regina	2.8	4.9	30.7	59	122.7	2.561
	Ruegen	2.8	3.2	29	62.3	143.7	2.875
	Alexandria	2.2	4.6	26.7	57.7	105.3	2.634
	Baron Von Solemacher	2.9	4.5	37.3	66	129.7	2.899

Source: *developed by the authors*

For plants of the "Regina" and "Alexandria" varieties, the introduction of limestone materials did not significantly affect this growth characteristic. There was also no significant effect of the soil pH value on the number of days before the appearance of the first visible flower buds and the ripening of the first fruits. However, this indicator had a significant impact on the number of flowers on the site for the entire flowering period for all the studied varieties of garden strawberries. It was shown that the number of flowers was on average 20% higher when using aluminium sulphate compared to the control variant. For the strawberry variety "Alexandria", this indicator was 130% of the results from the site that was not treated with pH regulators. The number of flowers in the areas treated with limestone materials was slightly lower than the control areas for all the studied varieties of garden strawberries. The total weight of fruits from the site directly correlated with the number of flowers and inversely with the pH value of the soil. The use of aluminium sulphate in the studied concentration demonstrated the greatest effectiveness for growing strawberry plants. The results show that the optimal soil pH for strawberries is shifted to a more acidic side, which can theoretically be explained by the greater bioavailability of nutrients.

The use of fertilisers had a significant impact on the growth characteristics of garden strawberries. Data on the effect of fertilisers and compost on the growth characteristics of strawberry plants of different varieties are shown in Table 3.

Table 3*. Influence of fertilisers and compost on the growth characteristics of garden strawberry plants*

	Variety	Number of whiskers per plant	Number of trifoliate leaves per plant	Days before flowering	Days before the first fruits ripen	Number of flowers from the plot	Fruit weight per plot (g)
N	Regina	2.8	5	28.3	62.7	130.3	2.645
	Ruegen	2.7	5.6	30.3	58.7	155.7	2.976
	Alexandria	2.4	4.5	25	53.3	112	2.765
	Baron Von Solemacher	3.1	6.1	34	65	137.3	2.988
VG	Regina	4.5	6.9	25.3	60.3	139.3	2.756
	Ruegen	3.9	8.7	27.3	57	162.7	3.051
	Alexandria	5	7.1	22.3	54.7	121.3	2.890
	Baron Von Solemacher	6.3	9.2	31.3	62.7	145.7	3.076
VB	Regina	2.9	4.8	24.7	59.7	172.3	2.831
	Ruegen	2.6	5.9	25.3	54	201.3	3.144
	Alexandria	2.6	5.1	21	60.3	156.7	2.917
	Baron Von Solemacher	3.3	6.7	29.7	61	178	3.114
VM	Regina	3.4	5.7	24.3	61	154.7	2.813
	Ruegen	3.8	6.2	29	55.7	176	3.077

Table 3, Continued

	Variety	Number of whiskers per plant	Number of trifoliate leaves per plant	Days before flowering	Days before the first fruits ripen	Number of flowers from the plot	Fruit weight per plot (g)
	Alexandria	3.3	4.9	23.7	51.7	134.3	2.987
	Baron Von Solemacher	4	7.1	33.3	64	142	3.054
VA	Regina	3.9	6.8	23.3	57.3	149.7	2.915
	Ruegen	3.7	7.2	24.7	56.3	188.7	3.354
	Alexandria	4.4	6.7	19.3	58	128.3	3.267
	Baron Von Solemacher	4.8	7.1	30	59.7	152	3.162
C	Regina	3.6	7.5	26.3	60	157.3	2.789
	Ruegen	4.1	7.8	27.3	56.7	172.3	3.073
	Alexandria	3.9	7.3	22.7	49.7	139.7	2.890
	Baron Von Solemacher	3.8	7.8	31	63	146.3	3.183

Note: *N – control areas, VG – VerdeGrow, VB – VerdeBloom, VM – VerdeMicro, VA – complex of all three synthetic fertilisers, C – compost*
Source: *developed by the authors*

The greatest positive effect on the number of whiskers formed by plants after two weeks of cultivation and the number of triple leaves at the time of the first flowering was demonstrated by VerdeGrow. The reason for this effect is probably an increased potassium content. The largest indicators of these growth characteristics were possessed by plants of the "Ruegen" variety. It is worth noting that all the tested fertilisers had a positive effect on the growing season of garden strawberries. The use of compost proved to be quite effective and showed results comparable to those in areas where VerdeMicro and VerdeBloom preparations were used. The use of both organic and synthetic fertilisers reduced the number of days before the first visible flower buds appear, as well as the duration of ripening of the first fruits. The most effective preparation was VerdeBloom, which may be conditioned by the high phosphorus content in this fertiliser. The best indicators were shown by the varieties "Regina" and "Alexandria", the effect on plants of the varieties "Ruegen" and "Baron Von Solemacher" was slightly lower.

The use of VerdeBloom, and a complex of all three fertilisers, significantly increased the number of flowers on the site for the entire flowering period. The use of compost also had a positive effect on this characteristic. The largest number of flowers was formed by strawberry plants of the "Ruegen" variety when using VerdeBloom. There was a significant increase in the total weight of fruits from the site when using organic and synthetic fertilisers. The highest productivity was demonstrated by plants of the varieties "Ruegen" and "Alexandria" in combination with all three fertilisers of the Verde line, which indicates the importance of a balanced content of all micro- and macronutrients. Data on the effect of the fungicide and mulching practice on the incidence of strawberry plant disease are shown in Table 4.

Table 4*. Effect of trichodermin and mulching practices on the incidence of garden strawberry diseases*

	Variety	Number of affected plants per site			
		Powdery mildew	Septoria	Brown spotting	Grey rot
Control plots	Regina	0	1.3	1.7	0
	Ruegen	0	0	0.3	0
	Alexandria	0	1	0	2.3
	Baron Von Solemacher	0	2	1.3	2.7
Trichodermin, 1 ml	Regina	0	0	0	0
	Ruegen	0	0	0	0
	Alexandria	0	0	0	0
	Baron Von Solemacher	0	0	0	0
Trichodermin, 0.5 ml	Regina	0	0	0.3	0
	Ruegen	0	0	0	0
	Alexandria	0	0	0	0
	Baron Von Solemacher	0	0	0	0.7

Table 4, Continued

	Variety	Number of affected plants per site			
		Powdery mildew	Septoria	Brown spotting	Grey rot
Trichodermin, 0.25 ml	Regina	0	0	0.3	0
	Ruegen	0	0	0	0
	Alexandria	0	0	0	1.3
	Baron Von Solemacher	0	1	0	2
Mulching	Regina	0	0.7	0	0
	Ruegen	0	0	0	0
	Alexandria	0	0.3	0	0.7
	Baron Von Solemacher	0	1.3	0.3	2.7

Source: *developed by the authors*

The most vulnerable to diseases were plants of the "Baron Von Solemacher" variety. The use of a fungicide in amounts of 1, 0.5, and 0.25 ml per site significantly reduced the frequency of infection of garden strawberry plants with diseases such as septoria, brown spotting, and grey rot. The use of mulching practices has also demonstrated significant effectiveness in controlling these fungal infections, although slightly less compared to fungicide. However, in the case of plants of the "Baron Von Solemacher" strawberry variety, mulching and using a fungicide in the amount of 0.25 ml per site did not demonstrate effectiveness in combating fungal diseases due to the high sensitivity of this variety. Data on the effect of the fungicide and mulching practice on the growth characteristics of garden strawberry plants of various varieties are shown in Table 5.

Table 5*. Effect of trichodermin and mulching practices on the growth characteristics of garden strawberry plants*

	Variety	Number of whiskers per plant	Number of trifoliate leaves per plant	Days before flowering	Days before the first fruits ripen	Number of flowers from the plot	Fruit weight per plot (g)
N	Regina	2.8	5	28.3	62.7	130.3	2.645
	Ruegen	2.7	5.6	30.3	58.7	155.7	2.976
	Alexandria	2.4	4.5	25	53.3	112	2.765
	Baron Von Solemacher	3.1	6.1	34	65	137.3	2.988
1T	Regina	3	6.8	26	61	156.7	2.867
	Ruegen	2.5	5.9	32	60	161.3	3.001
	Alexandria	2.8	6.2	23	51	135.3	2.987
	Baron Von Solemacher	3.3	6.6	35	63	166	3.127
0.5T	Regina	2.9	5.7	27	64	155.7	2.976
	Ruegen	2.8	5.6	31	62	151.3	3.016
	Alexandria	2.8	6.4	22	54	139.7	3.056
	Baron Von Solemacher	3.2	6.3	32	67	158.7	3.218
0.25T	Regina	2.9	6.1	27	61	135.7	2.645
	Ruegen	2.6	5.8	32	60	149.7	2.899
	Alexandria	2.7	4.6	24	55	108.3	2.765
	Baron Von Solemacher	3.6	6.9	31	64	143.7	2.988
M	Regina	3.1	5.7	27.7	63.3	129.7	2.901
	Ruegen	3	7.8	29	57.3	157.3	3.140
	Alexandria	2.8	5.5	24	53.7	123.3	2.907
	Baron Von Solemacher	3.6	7.2	33.7	64	129.7	3.177

Note: *N – control areas, 1T – 1 ml of trichodermin, 0.5T – 0.5 ml of trichodermin, 0.25T – 0.25 ml of trichodermin, M – mulching*
Source: *developed by the authors*

The positive antifungal effect allowed achieving slightly higher indicators of such vegetation characteristics as the number of whiskers that plants formed after two weeks of cultivation and the number of trifoliate leaves at the time of the first flowering. It is worth noting that the use of mulching practice led to an increase in these growth characteristics for the Ruegen variety, even though the plants of this strawberry variety were practically not affected by fungal infections in the control areas. A similar effect was not reproduced with the use of the fungicide. This indicates the existence of additional positive effects of mulching, in addition to direct infection control. The growth indicators of plants of the "Ruegen" variety in the control areas and areas that were treated with a fungicide did not differ significantly. The use of a fungicide and mulching practice did not significantly affect such indicators as the number of days before the appearance of the first flower buds and the duration of ripening of the first fruits. At the same time, the use of a fungicide in the amounts of 1 and 0.5 ml per site significantly increased the number of flowers for the entire growing season and the total weight of fruits from the site for all the studied varieties of garden strawberries. The most pronounced effect was observed for plants of the Baron Von Solemacher variety when using the maximum concentration of the drug. The practice of mulching did not significantly affect the total number of flowers from the site for the entire growing season, but its use led to an increase in the total weight of fruits, due to an increase in the average weight of individual berries. Data on the effect of insecticide in different amounts on the growth characteristics of garden strawberry plants of different varieties are shown in Table 6.

Most often, strawberry plants were affected by pests such as mole crickets, may beetle larvae, strawberry-blossom weevils, and strawberry mites. The use of insecticide in the amount of 6 and 3 mg per plot led to a significant positive effect in the control of garden strawberry pests, which was expressed in an increase in growth characteristics. The study preparation at maximum concentration resulted in an increase in the number of triple leaves at the time of first flowering and an increase in the number of whiskers after two weeks of cultivation for most of the studied varieties. The use of insecticide in the amount of 3 mg per plot increased the growth indicators of the growing season of strawberry plants of the "Regina" and "Ruegen" varieties. It is worth noting that the number of trifoliate leaves of plants of the "Regina" variety at the time of the first flowering slightly increased even with the use of the study drug in the amount of 1 mg per plot, which indicates a special sensitivity of this variety to pests.

***Table 6**. Effect of abamectin on the growth characteristics of garden strawberry plants*

	Variety	Number of whiskers per plant	Number of trifoliate leaves per plant	Days before flowering	Days before the first fruits ripen	Number of flowers from the plot	Fruit weight per plot (g)
N	Regina	2.8	5	28.3	62.7	130.3	2.645
	Ruegen	2.7	5.6	30.3	58.7	155.7	2.976
	Alexandria	2.4	4.5	25	53.3	112	2.765
	Baron Von Solemacher	3.1	6.1	34	65	137.3	2.988
6A	Regina	4.1	7	25.3	55.3	156.3	2.910
	Ruegen	3.5	5.9	27.3	54.7	187.7	3.303
	Alexandria	3.1	5.1	22.3	49.7	134.3	3.042
	Baron Von Solemacher	3.3	6.4	30.7	60.7	150	3.212
3A	Regina	3.6	5.7	24.7	59.7	147.7	2.777
	Ruegen	3.2	6.4	28.3	55.3	179.3	3.125
	Alexandria	2.6	4.7	23.7	49.3	128.3	2.903
	Baron Von Solemacher	3.1	6.3	32.7	61.3	145.3	3.137
1A	Regina	2.7	5.4	26.3	60.3	136.3	2.617
	Ruegen	2.9	5.4	28.7	54.7	172.7	3.007
	Alexandria	2.5	4.4	23	50.3	121	2.792
	Baron Von Solemacher	3.2	5.8	31.7	62.3	127.7	3.017

***Note:** N – control sites, 6A – 6 mg abamectin, 3A – 3 mg abamectin, 1A – 1 mg abamectin*
***Source:** developed by the authors*

The use of insecticide allowed reducing the number of days before the first visible flower buds appear by an average of 11% and the period required for the first berries to ripen by an average of 7% compared to the control areas. The most pronounced reduction in the ripening period of fruits by 12% was observed for strawberry plants of the "Regina" variety. The use of 6 mg of insecticide per site had a positive effect on the number of flowers during the entire flowering period and the total weight of fruits from the site. The highest results of fruiting productivity in this experiment were demonstrated by plants of the "Ruegen" variety when using the maximum amount of the test drug. It is worth noting that small concentrations of insecticide, namely 3 and 1 mg per plot, also had a positive effect on the total weight of fruits from the plot for most of the varieties of garden strawberries. The results obtained indicate that even low concentrations of insecticides can effectively eliminate this negative factor.

The growth of pest plants was observed in all areas where the herbicide was not used. The most pronounced growth was observed in areas where organic and synthetic fertilisers were used. When using the maximum amount of herbicide, it was possible to achieve complete elimination of pest plants at all experimental sites, but this led to a decrease in a number of indicators of strawberry plants themselves, which indicates the sensitivity of this crop to fluazifop-p-butyl. Data on the effect of herbicide in different amounts on the growth characteristics of garden strawberry plants of different varieties are shown in Table 7.

Table 7. *Effect of fluazifop-p-butyl on the growth characteristics of garden strawberry plants*

	Variety	Number of whiskers per plant	Number of trifoliate leaves per plant	Days before flowering	Days before the first fruits ripen	Number of flowers from the plot	Fruit weight per plot (g)
N	Regina	2.8	5	28.3	62.7	130.3	2.645
	Ruegen	2.7	5.6	30.3	58.7	155.7	2.976
	Alexandria	2.4	4.5	25	53.3	112	2.765
	Baron Von Solemacher	3.1	6.1	34	65	137.3	2.988
90F	Regina	2.2	4.7	27.3	63.7	114.7	2.546
	Ruegen	2.1	5.1	31.7	57	175.3	3.254
	Alexandria	1.9	4.6	26.3	52.7	98.7	2.645
	Baron Von Solemacher	2.5	5.8	35.3	64.3	120.7	2.872
60F	Regina	3.5	6.4	26	57.3	127.7	2.634
	Ruegen	3.4	7.2	25.7	49.7	176.3	3.199
	Alexandria	2.5	4.4	23	49.3	122.7	2.701
	Baron Von Solemacher	3.9	7.8	31.3	58.3	145	2.933
30F	Regina	3.3	5.2	27.7	63.3	132.7	2.654
	Ruegen	3.2	5.4	26.3	52.3	161	3.011
	Alexandria	2.8	4.7	24.3	51.7	109.7	2.785
	Baron Von Solemacher	3.7	5.9	32.3	63.3	148.3	2.876

Note: *N – control sites, 90F – 90 mcg fluazifop-p-butyl, 60F – 60 mcg fluazifop-p-butyl, 30F – 30 mcg fluazifop-p-butyl*
Source: *developed by the authors*

The greatest positive effect of the studied preparation was demonstrated on the growth parameters of the vegetation period, such as the number of trifoliate leaves at the time of the first flowering and the number of strawberry whiskers after two weeks of cultivation. This effect was observed due to the fact that strawberry plants are most sensitive to competition in the early periods of their growth. The introduction of herbicide in the amount of 60 micrograms per plot increased these indicators in garden strawberry plants of the varieties "Regina", "Ruegen" and "Baron Von Solemacher". The use of the test drug in the amount of 60 micrograms per site also reduced the periods required for the appearance of the first visible flower buds and berry ripening by an average of 8% and 12%, respectively. The most pronounced effect of reducing these periods was

observed for strawberry plants of the "Ruegen" variety when using an herbicide in the amount of 60 and 30 micrommes per plot, which indicates an increased sensitivity of this variety to pest plants. The introduction of the herbicide did not lead to a significant increase in the total number of flowers from one site during the flowering period and the total weight of fruits. The use of the test drug in the amount of 90 micrommes per site, on the contrary, led to inhibition of flowering and fruiting productivity of experimental sites. The exception was strawberry plants of the garden variety "Ruegen", which showed an increased number of flowers and total fruit weight even when using the maximum amount of herbicide, which suggests an increased tolerance of this strawberry variety to herbicides.

DISCUSSION

The pH value of the soil is an important factor that affects the growth and development of plants. According to G.W. Thomas (1996) the pH level determines the presence of nutrients and the activity of microorganisms in the soil. Different plants have different preferences for soil pH, and maintaining an optimal pH range for a particular species can contribute to better growth, yield, and overall crop health. A. Läuchli and S.R. Grattan (2017) have shown that if the soil pH is too low or too high, it can cause nutrient deficiencies, toxicity, and other problems that can negatively affect plant growth. Their findings suggest that too acidic soil can reduce the availability of essential nutrients such as phosphorus, calcium, and magnesium, leading to stunted growth, yellowing leaves, and other symptoms of nutrient deficiency. On the other hand, if the soil is too alkaline, it can reduce the availability of trace elements such as iron, manganese, and zinc, which can also lead to a corresponding deficiency and poor plant growth and fruit quality. According to G.M. Darrow (1966), the optimal soil pH for strawberries ranges from 5.7 to 6. In this paper, the pH of untreated soil was 6.5, which exceeds the limits of the optimal range established from literature sources. Reduction of this indicator by adding aluminium sulphate allowed improving the characteristics of the growing season of strawberry plants and increasing the number of flowers and the total weight of fruits from the site. This may indicate that the bioavailability of minerals for garden strawberries is higher at more acidic soil pH values. Maintaining this factor in the optimal range is essential to ensure that plants have access to the nutrients they need for healthy growth, flowering, and fruit formation.

Nitrogen, phosphorus, and potassium, often abbreviated as NPK, are three important macronutrients crucial for strawberry growth and development. Each of these nutrients plays a unique role in supporting the plant's physiological processes, including photosynthesis, energy production, and root, flower, and fruit development. The greatest stimulating effect in the early stages of strawberry plant development was demonstrated by VerdeGrow with a high potassium content. According to A.K. Srivastava *et al.* (2020), this macronutrient is involved in many aspects of plant growth, including water balance regulation, enzyme activation, and stem and root development. R. Johnson *et al.* (2022) have shown that proper potassium levels can help increase plant resistance to environmental stresses such as drought, cold, and heat. A mixture of all three fertilisers, including VerdeMicro, which also contains a significant amount of potassium, demonstrated a stimulating effect on fruit development, which is consistent with data from literature sources. According to A. Nakro *et al.* (2022) potassium is important for fruit quality, especially in terms of improving taste, colour, and texture.

VerdeMicro with a high nitrogen content has demonstrated significant effectiveness at all stages of strawberry plant development. According to the study by J. Wang *et al.* (2021), the bioavailability of nitrogen has been shown to have a positive effect on the growth of plant leaves and stems. This element is a key component of chlorophyll, and, therefore, is necessary for photosynthesis and the formation of new plant tissues. Data by S. Farjana *et al.* (2023) indicate that the correct level of nitrogen is crucial for the development of strawberry leaf plates, which can effectively photosynthesise and support fruit growth. G. Costamagna *et al.* (2020) reported that excessive levels of this element can lead to undesirable vegetative growth, reduced flowering and fruiting, and increased susceptibility to pests and diseases. The results obtained did not demonstrate a decrease in the intensity of flowering and fruiting when applying maximum nitrogen concentrations. The question of the effect of fertilisers on the susceptibility of strawberry plants to biotic factors requires further investigation.

The most effective preparation from the standpoint of stimulating flowering was VerdeBloom with a significant phosphorus content. L.T. Le *et al.* (2021) have shown that this element plays a crucial role in root development, flowering, and fruiting processes. It is involved in the generation of DNA, RNA, and ATP. The necessary levels of phosphorus can help strawberry plants form a strong root system, which is essential for absorbing nutrients and water. A.J. Abbott (1968) indicated that phosphorus is important for the development of strawberry flowers and fruits, which is also consistent with the results obtained. An important aspect of this study was the comparison of organic and synthetic fertilisers. The findings show that the use of compost shows results comparable to some of the tested fertilisers. Thus, the use of natural fertilisers allows achieving efficient cultivation of garden strawberries, which can reduce the intensity of use of synthetic fertilisers and, accordingly, the negative impact on the environment.

Fungal diseases can have a significant negative effect on the growth and yield of strawberries. According to S.T. Koike *et al.* (2007), the most common

pathogens of such diseases are fungi of the *genera Fusarium, Phytophthora, Botrytis, and Verticillium*. During the experiment, *Botrytis cinerea* (Grey rot) fungi posed a significant problem for a number of garden strawberry varieties under study. M. Panth *et al.* (2020) have shown that fungal diseases can lead to a delay in plant growth and a decrease in their overall growth rates, which can lead to a decrease in yield. The use of trichodermin and mulching practices allowed eliminating the negative effects of infectious agents, which led to an increase in the growth parameters of strawberries. The "Baron Von Solemacher" garden strawberry variety turned out to be the most sensitive to fungal diseases, so the effect of using a fungicide and sanitary practice was the most pronounced for it. Mulching showed a positive effect on the growth parameters of strawberries, even for those varieties that suffered little from infections. J.P. Pinto *et al.* (2022) claim that mulching helps retain moisture in the soil, reducing the need for frequent watering. This is especially important for strawberries, which have shallow roots and are sensitive to drought. D. Neri *et al.* (2021) have shown that mulching can suppress weed growth by reducing competition for water, nutrients, and light. According to M. Meyer *et al.* (2021), mulching has been shown to help lower soil temperature, keeping it cooler in hot weather and warmer in cold weather. During heavy rains, mulching can help prevent soil erosion by reducing runoff and holding it in place during heavy rains. When mulching breaks down, it turns into a kind of organic fertiliser that promotes root growth and overall plant health. Thus, the results obtained regarding the effectiveness of mulching practices for growing garden strawberries are consistent with the data of other researchers. The results of this study showed that mulching shows an effect comparable to low concentrations of trichodermin and can serve as a more environmentally friendly alternative to the use of fungicides.

Insect pests can have a significant negative impact on strawberry plants and their fruits. According to S. Lahiri *et al.* (2022), this may include a decrease in yield, a decrease in fruit size, their deformation, and premature rotting of plants. The results obtained partially confirm this, because the use of insecticide made it possible to increase the total weight of strawberry fruits from the site. However, this effect was observed not by increasing the size of fruits, but by increasing their total number. The most resistant to pests was the "Ruegen" garden strawberry variety. This variety also proved to be the most sensitive to plant pests and at the same time the most resistant to the negative effects of high concentrations of fluazifop-p-butyl. The findings showed that even small amounts of insecticide and herbicide show a significant positive effect on the growth characteristics of garden strawberries. By reducing the use of these drugs, farmers can reduce the negative impact on the environment, while maintaining high productivity of strawberry plants.

CONCLUSIONS

The study considered the impact on the growth characteristics of different varieties of garden strawberries of such factors as the introduction of soil pH regulators, the use of organic and synthetic fertilisers, the use of different concentrations of trichodermin, abamectin and fluaziphop-p-butyl, and the use of mulching practices was tested. It was found that the introduction of aluminium sulphate in the amount of 200 g per plot of three square metres to reduce the pH value of the soil has a positive effect on the efficiency of growing strawberry plants of the varieties under study. The reduced pH of the soil turned out to be more optimal for this type of plant. The use of both organic and synthetic fertilisers allowed increasing the growth characteristics of the growing season, reducing the time before flowering and fruiting, and increasing the productivity of garden strawberry plants. The most pronounced effect on the characteristics of the growing season, such as the number of whiskers from the plant and the number of triple leaves in the second week of cultivation, was demonstrated by the drug with a high potassium content VerdeGrow. VerdeBloom, which contains a significant concentration of phosphorus, most effectively improved the characteristics of the flowering period. The combination of all three synthetic fertilisers under study had the highest positive effect on the productivity of garden strawberries.

In the course of the work, it was shown that the effectiveness of compost is also quite high and comparable to the use of VerdeMicro. Trichodermin concentrations of 1, 0.5, and 0.25 ml per three square metres eliminated the effects of fungal infections on strawberry plants for most of the varieties. At the same time, the practice of mulching also showed a significant positive effect on the growth characteristics of garden strawberries. Abamectin in amounts of 6, 3, and 1 mg per three square metres was effective for controlling insect pests. The use of fluazifop-p-butyl in amounts of 60 and 30 microgrammes per three square metres reduced the negative impact of plant pests. At the same time, at a concentration of 90 microgrammes per site, this drug reduced the growth characteristics of most of the strawberry varieties under study. The findings show that the use of organic fertilisers, natural farming practices, and the use of a reduced amount of herbicides and insecticides facilitates high productivity of garden strawberry plants. The obtained data allow adjusting the approach to growing this type of plant towards greater environmental friendliness and productivity. The effectiveness of using combinations of these factors requires further investigation.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Особливості вирощування суниці садової у відкритому ґрунті

Ермір Шахіні
Викладач
Університет Александра Мойсіу в Дурресі
2001, вул. Курріла, 14, м. Дуррес, Албанія
https://orcid.org/0000-0002-0083-1029

Айтен Берксоллі
Доктор філософії
Сільськогосподарський університет Тирани
1025, вул. Паїсі Водіца, м. Тирана, Албанія
https://orcid.org/0009-0004-4912-5207

Олег Анатолійович Коваленко
Доктор сільськогосподарських наук, доцент
Миколаївський національний аграрний університет
54008, вул. Георгія Гонгадзе, 9, м. Миколаїв, Україна
https://orcid.org/0000-0002-2724-3614

Наталія Валентинівна Маркова
Кандидат сільськогосподарських наук, доцент
Миколаївський національний аграрний університет
54008, вул. Георгія Гонгадзе, 9, м. Миколаїв, Україна
https://orcid.org/0000-0001-6169-6978

Юрій Володимирович Задорожний
Старший викладач
Миколаївський національний аграрний університет
54008, вул. Георгія Гонгадзе, 9, м. Миколаїв, Україна
https://orcid.org/0000-0003-3499-7753

Анотація. Метою цього дослідження було оцінити ефективність вирощування суниці за використання регуляторів pH, синтетичних та органічних добрив, практики мульчування та застосування фунгіцидів, інсектицидів і гербіцидів. Рівень pH ґрунту регулювали шляхом внесення сульфату алюмінію та вапняку у кількості 200 та 900 г на три квадратних метри відповідно. Для перевірки дії добрив використовували синтетичні препарати з різними макро- і мікроелементами, а також органічний компост. Оцінювали ростові характеристики вегетаційного періоду, включаючи показники цвітіння та плодоношення. Результати показали, що зниження pH ґрунту позитивно впливає на ефективність вирощування досліджуваних рослин. Застосування добрив з високим вмістом калію збільшувало швидкість проходження вегетаційного періоду, а препарати, багаті на фосфор, позитивно впливали на характеристики періоду цвітіння. Застосування компосту забезпечило збільшення продуктивності суниці, порівнянне з використанням синтетичних добрив. Доведено, що мульчування знижує ризик розвитку грибкових інфекцій у рослин та підвищує показники росту. Застосування гербіциду було значно ефективнішим для пригнічення росту рослин-шкідників та покращення ростових характеристик суниці. Показано, що застосування методів органічного землеробства та знижених концентрацій гербіцидів та інсектицидів дозволяє досягти високої ефективності вирощування суниці

Ключові слова: ростові характеристики; органічне землеробство; синтетичні добрива; мульчування; плодово-ягідні культури

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 26(7), 118-128

UDC 581.1: 633.4
DOI: 10.48077/scihor7.2023.118

Adaptive abilities of chard cultivars

Altynay Idrissova*
PhD Student
Kazakh National Agrarian Research University
050010, 8 Abai Ave., Almaty, Republic of Kazakhstan
https://orcid.org/0000-0003-1587-4408
Zhangul Zhumaguloga
PhD, Professor
Kazakh National Agrarian Research University
050010, 8 Abai Ave., Almaty, Republic of Kazakhstan
https://orcid.org/0000-0003-3589-8001
Gulnar Myrzabayeva
PhD in Agricultural Sciences, Professor
Kazakh National Agrarian Research University
050010, 8 Abai Ave., Almaty, Republic of Kazakhstan
https://orcid.org/0000-0002-3482-3641
Kurmankul Abayeva
Doctor of Agricultural Sciences, Professor
Department of Forest Resources, Game Management and Fisheries
Kazakh National Agrarian Research University
050010, 8 Abai Ave., Almaty, Republic of Kazakhstan
https://orcid.org/0000-0003-3092-5015
Mukhit Bekbauov
PhD in Agricultural Sciences. Associate Professor
Kazakh National Agrarian Research University
050010, 8 Abai Ave., Almaty, Republic of Kazakhstan
https://orcid.org/0000-0001-9161-0792

Article's History:
Received: 27.04.2023
Revised: 24.06.2023
Accepted: 7.07.2023

Abstract. The method of growing green vegetable crops in a greenhouse equipped with modern technologies allows controlling humidity, light, temperature, carbon dioxide levels, air circulation and much more. With the help of information and digital technologies, the growth rate of cultivated crops is controlled, yields are increased, and the use of water and resources is more efficient than with traditional cultivation methods. Based on the research work carried out in the period 2020-2022. according to the technology of growing chard sowing in closed greenhouses in Almaty, the Republic

Suggested Citation:
Idrissova, A., Zhumaguloga, Zh., Myrzabayeva, G., Abayeva, K., & Bekbauov, M. (2023). Adaptive abilities of chard cultivars. *Scientific Horizons*, 26(7), 118-128. doi: 10.48077/scihor7.2023.118.

*Corresponding author

of Kazakhstan, an assessment of agrobiological properties, productivity, and adaptability was made. The purpose of the article is to study the range of chard varieties and assess the influence of soil properties, temperature, and illumination on productivity, biochemical composition, and biological activity. The following methods were used in the studies: laboratory – including monitoring and evaluation of the biochemical composition of plant material; biometrics – assessment of the parameters of a comprehensive analysis of the environment and the qualitative characteristics of the crop; phenology – observation of the phases of development; statistics – analysis of information to assess the adaptive capabilities of chard. A wide range of tolerance to growing conditions was observed in the Mercury and Buru varieties, a moderate one in the Bull's Blood and Bride varieties, and a narrower one in the Rubin variety. Under greenhouse conditions, the duration of vegetation in the spring turnover was 45-56 days: variety Mercury v 55 days, Buru – 50 days, Bull's blood – 45 days, variety Bride – 53 days and Rubin – 55 days, respectively. For three years of cultivation, the average yield of chard was Mercury – 5.27 kg/m^2, Buru – 4.51 kg/m^2, Rubin – 4.86 kg/m^2, Bride – 5.09 kg/m^2, Bull's blood – 5.54 kg/m^2. In the conditions of 2022, active accumulation of photosynthetic material took place in the leaves of most chard varieties. In particular, the practical significance of the methods of growing green vegetables in greenhouse conditions, the organizational and economic processes of greenhouse cultivation, the study of economic and biological characteristics and the yield of various chard varieties form the development strategy for the vegetable growing industry

Keywords: variety; greenhouse; biochemical composition; productivity; biological activity

INTRODUCTION

Growing environmentally friendly vegetable products in protected ground conditions is an important strategic task of the agro-industrial complex of the Republic of Kazakhstan (RK). The modern understanding of rational and proper nutrition requires the consumption of a sufficient amount and an increase in the range of green vegetable products, which allows diversifying the nutrition of the population to a certain extent. RK is one of the most developed agricultural regions with great potential, but indoor cultivation of early ripe and green vegetables remains a significant problem. According to the Greenhouse Association of Kazakhstan (2023), today there are more than 1.8 thousand hectares of land under greenhouse facilities in the country, from industrial complexes to mini-greenhouses. On the basis of the association, training courses for consultation and support are organized, as well as the management of international exhibition centres for managers and agronomists of greenhouse farms.

In their work, N. Asylkhan and N.T. Dauzhanov (2022) report that the production of green crops in the Republic of Kazakhstan is insufficient and accounts for about 2% of the total vegetable production, while in the European Union (EU) – more than 30%. According to K. Zhambakin and K. Zhapar (2020) overcoming the seasonality of greenhouse cultivation and year-round consumption of vitamin products is an important task, but to solve it, it is necessary to improve the structure of vegetable growing by introducing new valuable vegetable plants, creating varieties and hybrids for different growing regions; creation and use of preparations for the protection of plants from diseases and pests; application of new biotechnological methods for environmental protection; increase in productivity and precocity with the expansion of the zone of distribution of vegetables.

D. Wang *et al.* (2022) argue that the species diversity of plants available for cultivation in the Republic of Kazakhstan and the methods of their cultivation, collection, storage, and use depend on the following factors: the natural and climatic conditions of the region, national traditions, modern food culture and technical capabilities, as well as the availability of suitable premises for growing and storing products. In agricultural crop production, about 20 thousand plant species are grown and consumed, of which 15 thousand are vegetable-growing. In the industrial vegetable growing of the Republic of Kazakhstan, about 40-50 types of green vegetables are grown, while in personal subsidiary plots the range reaches up to 150 types of plants.

S. Ajibade *et al.* (2022) assessed chard, chard, which widely distributed in EU countries, China, Georgia, Armenia, Turkey, USA, Japan, and India. Chard has its origins in the Mediterranean, but is most commonly grown in Switzerland, where it is known as Swiss chard. Vegetable growers need to pay more attention to the cultivation and use of this species, which can offer a wide range of vitamin products among green vegetables. Chard differs from red beets in that it has no roots, and the leaves are edible, as well as the presence of a two-year growth cycle: in the first year, green inflorescences are harvested, and in the second year, in addition to the green mass, seeds ripen.

A.B. Idrisova *et al.* (2022) described the chard depending on the shape and cut of the leaves: petiolate and leafy. Leafy chard is characterized by a lush rosette of large, fleshy leaves and narrow petioles, cultivars and hybrids called Romaine Kale or Spinach Kale can easily be used in place of leafy vegetables such as spinach, lettuce, and other leafy green vegetables. Petioled chard form bushes with numerous large stems. The leaves of these varieties are smaller, but the petioles

are very tasty, juicy, replacing asparagus celery in the diet. To achieve larger stems, when growing chard, the leaves are cut off, leaving the petioles.

I. Gonzalez-Fernandez *et al.* (2016) give a detailed description of chard varieties according to varietal differences that differ in stem colour: whitish, yellowish, light green and dark green, red. Leaves can be either curly or smooth. Lyon chard is distinguished by a low but powerful rosette of delicate, salad-coloured leaves. Swiss chard is characterized by erect, yellow-green, blister-curly and relatively large leaves. Chard-Lukullus is characterized by larger and curly leaves than those of the Swiss, with a white wide petiole. Silver curly chard has heavily curly-bubbly leaves. Silver smooth chard differs from the previous variety – smooth waviness. Yellow-petiolate chard is an ornamental variety with bright yellow petioles. The red-petiolate variety of Mangold is early ripening, and forms a large, compact rosette of slightly wavy dark green leaves. The Petioles are slightly ribbed, bright red, of medium width within 3-4 cm. The Dark green chard is mid-ripening, its rosette consists of highly raised wavy-bubble green leaves, petioles are slightly ribbed, white, of average width within 4-6 cm.

The purpose of this study is to study the spectrum of varieties with low distribution and to evaluate the influence of greenhouse soil characteristics, moisture, and light conditions on the yield, biochemical composition and biological activity of chard.

THEORETICAL OVERVIEW

Chard (*Beta vulgaris L. var. cicla*) is a biennial herbaceous plant that belongs to the amaranth family (*Amarantháceae*), one of the varieties of leaf beet with a wide rosette, large leaves and short stems, besides, contrasting veins give the culture a special elegance. H. He *et al.* (2022) in their work report that based on the DNA analysis of two geographic groups of chard (African and North American), a gene pool sequence was established, including 7 sections *Lactuca and Lactuca Cyanicae, Phoenixopus, Mulgedium, Lactucopsis, Tuberosae, Micranthae and Sororiae*.

S.P.A. de Oliveira *et al.* (2021) characterize vegetable crops, including chard, which is the least demanding on growing conditions and is not afraid of diseases and pests. Having a long root, the chard easily tolerates a dry period and is resistant to low temperatures. In the period of 25-40 days after the appearance of sprouts, it produces marketable products, and the leaves are constantly renewed during the summer and autumn. As noted by A. Libutti *et al.* (2023), the yield of chard is very high. From one square meter, it is possible to get up to 30 kg of leaves and up to 10 kg of cuttings per season, while the yield of spinach is about 5-6 kg. Chard is cold-hardy and drought-tolerant. Chard is grown by sowing seeds into the soil, leafy forms are sown in mid-April with a row spacing of 25-30 cm, and petiolate Common chard 45-60 cm, it is also allowed to re-sow in July. The seeding rate is 5 g per 1 m^2. The sprouts are thinned out, leaving the plants at a distance of 8-10 cm, and then – 15-20 cm.

R. Brown and R. Gbesbm (2021) note the following types of chard: according to the shape of the leaves – narrow and long; petioles are tall and fleshy. Chard leaves are classified into horizontal, sinuous, with a smooth or blistered surface, round, oval, elongated; entire and with serrated edges. The root system of the chard is rather weak, but regenerates well and grows quickly, so the plants easily tolerate transplantation, but at the same time require constant uniform soil and moisture. Chard varies in colour from light yellow and dark green to dark red, with some varieties having distinctive anthocyanin spotting and leaf margin pigmentation. The stem of the chard is highly developed and reaches 4-5 cm or more in diameter.

Z.T. Teshome (2022) reports that soil cultivation of chard requires loosening and weeding during the growing season. The best predecessors of chard are potatoes and nightshade vegetables. During dry periods, increased watering after cutting the leaves is recommended. If a soil crust has formed, there is not enough air in the ground, with a prolonged decrease in temperature, waterlogging of the soil, its increased acidity, diseases can develop on crops, in particular root rot and black leg.

M.K. Bozokalfa *et al.* (2011) concluded that chard leaves and stems are rich in protein, monosaccharides, and a high content of ascorbic acid was also noted – 30 mg%. The content of B vitamins indicates numerous macro- and microelements in easily digestible chelate forms in the form of sodium, iron, chlorine, calcium, phosphorus ions, etc. Leaves and petioles rich in vitamins are eaten fresh and boiled. Chard roots are not edible. The plant has a high decorative value and is good for health.

Z. Mzoughi *et al.* (2019) when creating a new variety of chard recommends using the method of individual-family selection for 7 generations from a hybrid population obtained by free cross-pollination of varieties. M. Gamba *et al.* (2021) described changes in the productive characteristics of the variety carried out according to the following indicators: high stable yield of green mass over the years; leaf blade with anthocyanin frame; rounded relatively large root crop, which is characterized by high keeping quality during storage of mother liquors, ensuring the suitability of using beam products together with the root crop; the ability of leaves to grow back after cutting; resistance to biotic and abiotic environmental factors; resistance to the formation of flowering shoots in the second year of vegetation; high seed productivity.

MATERIALS AND METHODS

The following methods were used in the study: laboratory – included monitoring and evaluation of the biochemical composition of plant material;

biometric – parameters of a comprehensive analysis of environmental conditions and qualitative characteristics of the variety and yield; phenological – observations of the stages of plant ontogenesis; statistical – analysis of information on assessing the adaptive abilities of chard.

In order to expand the range of green vegetable products in the period 2020-2022, in accordance with generally accepted methodological recommendations and taking into account the biological characteristics of species, studies of chard were carried out in innovative closed greenhouses based on Kazakh National Agrarian Research University, Almaty. Estimate morphological signs of chard sowing carried out according to Order of the Minister of Agriculture of the Republic of Kazakhstan No. 06-2/254 "Methodology of the State variety testing of agricultural crops" (2011). To study the adaptive abilities of sowing chard, the sowing of the varieties Mercury, Buru, Rubin, Bride, and Bull's blood was carried out, and the morphological-identification, biometric and biochemical characteristics of the crop were evaluated. The soils of greenhouse plots are represented by chernozem with a humus content of 3 to 6%, leached, heavy loamy typical for the southeast of the Republic of Kazakhstan for signs and properties.

The total area of the greenhouse was 500 m^2, by design it was divided into 2 sections of 250 m^2. Layered and pyramidal structures allowed more than 4 floors with shelves. The number of rows of the pyramid in which the plants were planted consisted of 8-9 tubes. A favourable microclimate was provided by automated irrigation, air conditioning, lighting, and ventilation systems at all levels. Before sowing seeds and seedlings in the greenhouse, the equipment, cassettes, and substrates used were sterilized.

Planting of seedlings in the spring turnover of closed greenhouses was carried out in the second decade of April according to the scheme 20×15 cm. The depth of planting seeds in the soil was between 2.5-3 cm. The optimal distance between rows was 25 cm. The seeds were sifted at a distance of 1 cm. The location of the plots was randomized with quadruple repetition.

During the growing season of chard sowing, phenological observations of sowing, mass shoots, technical ripeness and biometric measurements (height and diameter of the leaf rosette, number of leaves, thickness, and length of the petiole) were carried out in the research and scientific National Agrarian Research University. The chard varieties of the 2020-2022 sowing crop were analysed for the content of total sugar by the Bertrand method; dry matter by drying in a thermostat at 105°C to constant weight; ascorbic acid by titration with Tillmans stain; the content of pigments carotene, chlorophyll A and B was carried out on a gasoline extract by the spectrophotometric method at a wavelength of the spectrophotometer 450, 663 and 645 nm, respectively. In laboratory conditions, the seed suitability of chard for seed germination and germination energy was determined, which on average for all varieties was 93-97%.

Statistical processing of experimental data on yield, biometric and biochemical indicators of chard sowing was carried out by the method of analysis of variance for the reliability of the difference between the average values using the dispersion method based on the data of S.M. Lourenço (2019).

RESULTS

To expand the range of vegetable products, varieties of chard were studied in a greenhouse; they differed in the colour of the stems and the roughness of the leaves. In some varieties, the stems are better tasting than the leaves, like rhubarb and celery. The most promising are:

1. The chard variety Mercury – from early ripening, growing season – 55 days, before harvesting 95 days, the average yield is 4.4-4.9 kg/m^2. The variety is marked by a semi-vertical arrangement of large leaves. The leaves are intensely coloured red with an anthocyanin tinge. In terms of taste, it has a delicate, crisp texture of leaves with a folded surface. The rosette is 27 cm high, and the diameter of the rosette is 27-31 cm. The approximate weight of one plant is 450 g. The seeds are sown in April-May. When grown for seedlings, seeds are sown in March-April, and planted in May. To form a powerful rosette, regular and moderate watering is required to prevent stagnation of water and drying of the soil substrate.

2. The chard variety Buru is mid-season, the growing season is 48 days, before harvesting 85 days, the yield is 4.2-4.8 kg/m^2. Representatives of Buru chard have an upright rosette of leaves, slightly spreading in the upper part, 54-61 cm high. The leaf is large, elongated-oval, purple-green. The edge is slightly wavy. The surface is slightly bubbly. The length of the leaf blade is 23-25 cm, the width is 16-17 cm. The length of the petiole is 27 cm, the colour is raspberry-red, with the presence of anthocyanin.

3. The chard variety Bride is a mid-season variety that takes 55 to 65 days from germination to harvest. Young leaves and stalks of chard contain many vitamins and minerals. The leaf rosette is upright, compact, up to 60 cm high. The leaves are medium, dark green, slightly bubbly, tender and tasty. Petioles are long, wide, juicy, golden-white, 30-45 cm long. This variety is relatively drought-resistant and cold-resistant. Sow in open ground to a depth of 2.5 cm at the end of April. Multiple cleaning included. The yield of leaves and petioles is 6-7 kg/m^2.

4. The chard variety Rubin is a mid-season species, which is represented by a medium-sized rosette, consisting of green leaves with red veins and petioles. When grown directly in the ground, seeds are sown in early May; seedlings are planted in mid-May. The leaves begin to bear fruit 35-40 days after germination. The greens are harvested several times during the summer.

The plant is cold-resistant, prefers humidity, with purple-green leaves and dark red petioles 20-30 cm long.

5. The chard variety Bull's blood is a mid-season species, the growing season from germination to mass harvesting is observed within 100-110 days. The variety can be grown for microgreens. The variety has a rich ruby colour, without white streaks, and with frost, the colour of the foliage intensifies. The leaves of the variety are rounded and smooth, delicate and soft in taste. The yield of leaves and petioles is 4-5 kg/m^2.

It is important to establish microclimate parameters for the formation of chard sowing due to changes in biometric indicators. Not only the quantity of the crop, but also its quality characteristics, depended on the growing conditions. The taste of the leaves and stem of chard is affected by: the composition of the soil, adherence to agricultural practices, optimal temperature, lighting and other factors.

Common chard was sown in fertile, loose, well-watered soil, as on poor, heavy clay soils with an acidity below pH 6, the leaves will be rougher and the taste will be worse. Chard does not tolerate waterlogging, so planting in stagnant soils is not allowed. Crop rotation was also taken into account, since in one place chard and beets are grown at intervals of 3-4 years. When choosing a site, crop rotation rules are observed, recommended predecessors: carrots, radishes, legumes, tomatoes, cucumbers, radishes, do not grow well after spinach and fodder root crops. In autumn, nutrient components were introduced into the soil to a depth of 30 cm: compost, peat, humus, or other organic fertilizers – 4-5 kg per 1 m^2; superphosphate – 20-25 g; potassium chloride – 15-20 g. Also, often, in heavy soils, dense and clayey, sand is added to loosen the structure. The optimal temperature for growing chard is 16-25°C, the flowering period is 20-25°C, with good watering, growth is possible at 35°C. Seeds germinate at a temperature of 6-7°C. Young plants with 3-4 true leaves can tolerate low temperatures down to -3°C.

When planting in partial shade, it should be borne in mind that due to lack of sunlight, nitrates, and nitrites can accumulate in the leaves, and prolonged shading can slow down growth and cause the leaves to become small. Chard grows well in both full sun and partial shade and requires a lot of light, but keep in mind that the less light, the more delicate the taste of the leaves and the lower the yield. Conducted phenological observations on average for 2020-2022 assumed to take into account the beginning and main phases of the development of chard varieties. It is noted that the bequeathing stage of growth occurred with the appearance of 8-10 leaves, data on all studied varieties are noted in Table 1.

Table 1. *Duration of phenological phases of leafy chard varieties*

Varieties	The period from sowing to the growth of shoots, days	Period from sowing to, days			
		Real 1 sheet	Real 3-4 sheets	Real 8-10 sheets	End of the growing season
Mercury	4	18	31	55	94
Buru	4	16	30	48	84
Ruby	5	17	32	55	96
Bride	6	16	31	53	95
Bull's blood	4	15	31	45	85

Source: *compiled by the authors*

Under the conditions of hydroponic cultivation, the first shoots were observed on the 5-6th day after sowing the seeds. Varieties of the studied chard with the appearance of 10 leaves or vegetative ripeness, were established during the period from sowing: 55 days – the Mercury variety, 50 days – the Buru variety, 45 days – the Ox's blood variety, 53 days – the Bride variety, 55 days – the Rubin variety. The studied samples differed not only in the rate of development, but also in biometric parameters according to the averaged data for 2020-2022, Table 2 shows the data of chard varieties during harvesting in the spring turnover when grown in a closed greenhouse.

Table 2. *Biometric indicators of chard varieties*

Varieties	Rosette height, cm	Outlet diameter, cm	Number of leaves, pcs
Mercury	22.4±0.15	33.5±0.07	23.2±0.12
Buru	22.3±0.51	33.5±0.13	24.5±0.45
Ruby	21.3±2.05	33.0±2.44	24.3±2.67
Bride	26.9±1.05	33.6±1.18	24.4±0.85
Bull's blood	30.7±1.83	34.5±1.40	29.4±1.95

Source: *compiled by the authors*

The reactions of varieties to greenhouse growing conditions are manifested by the degree of variability of biometric parameters, which are divided into three groups:

1. Wide range of tolerance to the conditions of the variability of all biometric parameters less than 10% (Mercury and Buru);

2. The average range of tolerance to the conditions of the variability of at least one biometric indicator by 10-20% (Bull's blood and Bride);

3. A narrow range of tolerance to the conditions of the variability of at least one biometric indicator is more than 20% (Rubin).

Chard cultivars Mercury, Buru, Rubin, Bride, and Bull's blood formed medium-sized rosettes with a leaf height of 21.3-30.7 cm, and a rosette diameter of 32.3-34.5 cm. 29 pcs. Accounting for the yield of the leaf mass of chard sowing was carried out separately according to variants and repetitions. Changes in greenhouse conditions for the current 2020-2022 research, identified varietal differences in the formation of the crop, which are detailed in Table 3.

Table 3. *Productivity and marketability of chard varieties*

Varieties	Productivity kg/m ^{2}			Average plant weight, g	Marketability, %
	2020	2021	2022		
Mercury	4.90	5.56	5.34	204	92
Buru	4.77	4.23	4.53	197	86
Ruby	4.94	4.75	4.89	198	87
Bride	5.12	4.99	5.15	198	88
Bull's blood	5.16	5.45	6.02	222	95

Source: *compiled by the authors*

When evaluating the yield, it was found that in the varieties of chard Bride, Rubin, Mercury, Buru – 4.8-5.6 kg/m^2, these indicators were inferior to the variety Bull's blood – 5.5 kg/m^2. Similarly, there was a trend in terms of average weight and marketability. Given the difference in growing conditions over the years, the yield of chard varieties changed. In 2020, moderate direct illumination of plants was used, with an average daily temperature in May of 13-18°C. In 2021, a high level of direct illumination was noted with an average daily temperature in May of 16-20°C. In 2022, moderate conditions of a high level of illumination were established with an average daily temperature in May of 14-19°C. Biochemical analysis of leaves for the content and ratio of energy pigments – chlorophyll (A, B) and carotenoids for the period 2020-2022 is noted in Table 4.

Table 4. *Composition and content of pigments*

Varieties	Years of cultivation	Chlorophyll, mg/g		Carotene, mg/g
		A	B	
Mercury	2020	0.42	0.31	0.18
	2021	0.39	0.44	0.16
	2022	0.40	0.37	0.23
Buru	2020	0.57	0.63	0.11
	2021	0.59	0.59	0.09
	2022	0.43	0.54	0.14
Ruby	2020	0.61	0.58	0.15
	2021	0.57	0.31	0.10
	2022	0.47	0.56	0.12
Bride	2020	0.48	0.74	0.15
	2021	0.46	0.24	0.07
	2022	0.65	0.72	0.18
Bull's blood	2020	0.41	0.52	0.23
	2021	0.59	0.78	0.14
	2022	0.12	0.68	0.24

Source: *compiled by the authors*

The content of chlorophylls A and B, regardless of the variety, decreased relative to the increase in temperature and the level of direct solar energy in the greenhouse during the period from 2020 to 2022. The total content of pigments in the leaves of the varieties Bull's Blood and the Bride is higher, in contrast to Mercury, Buru and Rubin. In the Bull's blood variety, a low content of chlorophyll A was noted, due to the individual composition of this variety, but it was compensated by the content of carotene. The results of biochemical research in 2020-2022 are detailed in Table 5.

Table 5. *Biochemical composition of chard varieties, %*

Varieties	Years of cultivation	Dry matter	total sugar	organic acids
Mercury	2020	94.26	0.94	0.44
	2021	94.88	0.82	0.32
	2022	94.21	0.84	0.26
Buru	2020	94.35	1.18	0.48
	2021	94.96	1.16	0.56
	2022	94.56	1.24	0.47
Ruby	2020	94.55	1.15	0.34
	2021	94,.24	1.42	0.36
	2022	95.52	1.08	0.42
Bride	2020	94.83	0.64	0.64
	2021	95.02	0.38	0.56
	2022	94.80	0.62	0.66
Bull's blood	2020	94.69	1.27	1.28
	2021	95.62	1.47	1.31
	2022	94.24	1.87	1.22

Source: *compiled by the authors*

The biochemical composition of chard leaves is diverse, but the content of individual components is low. The accumulation of dry matter, sugars and organic acids, regardless of the variety, was more active in 2022. In the Bull's Blood variety, a high content of dry matter was noted 94.2-95.6%, total sugar – 1.3-1.9%, organic acids – 1.2-1.3%.

DISCUSSION

Greenhouse farming can provide an increase in crop yields throughout the year. At the same time, agricultural producers have more and more opportunities to control and create the optimal climatic conditions necessary for plant growth. It has been established that the greenhouse cultivation of chard increases the productivity and taste of chard, as well as the yield, which averaged 4.2-6.0 kg/m^2 in comparison with the cultivation of these crops in open ground. Optimal greenhouse conditions, increased carbon dioxide concentration enhance photosynthesis, leading to highly efficient vegetable growing in a shorter time compared to open ground. In general, when analysing biometric data, greenhouse cultivation was higher in almost all indicators, but the Bull's blood variety turned out to be the leader with an average annual yield of 5.54 kg/m^2, as well as plant height, rosette diameter and a number of leaves were the largest. Staying in the enclosed space conditions of a greenhouse prevents damage to crops from climate change, rising or falling temperatures, possible drought, and keeping birds and other animals away from crops.

H. Kabir *et al.* (2018) found that yields per m^2 increase threefold or more when greenhouses are implemented in combination with digital technologies and hydroponics strategies. The light period of greenhouse conditions during the daytime lasts 16 hours, and at night – 8 hours, the optimum temperature was at the level of 23°C, relative humidity 70%, the allowable values of CO_2 in the air were 1000 ppm or in terms of a percentage of 0.1%. F.J. Rodriguez Pulido *et al.* (2022) compare greenhouse conditions for chard cultivation with alternative open-field farming, where the yield of commercial chard cultivation is in the range of 2-2.5 c/ha, although it is quite possible to increase the yield in the range of 8-10 c/ha.

Chard at different stages of development does not consume the same amount of water, it especially needs high soil moisture during seed germination and in the

first weeks after germination, so it is recommended to sow in spring in moist soil. Uneven rainfall or watering carried out with long interruptions adversely affect growth, as well as the emergence of seedlings stretched over time. V. Zunic *et al.* (2022) argue that as a result of more efficient use of resources, less waste can be generated, which contributes to greener production, which in turn can lead to increased profits. Leafy vegetables such as chard, basil, microgreens, arugula, spinach are increasingly grown in hydroponic or semi-hydroponic systems. With the growing popularity of organic food production, growing vegetables in organic conditions, without the use of inorganic fertilizers or chemical plant protection products, and using a greenhouse environment for growing and cultivating chard is the basis for modern methods for the production of functional foods.

Biometric measurements of height, diameter, and number of leaves in a rosette in chard varieties depend on varietal characteristics. In general, in the analysis of biometric data, the leader in almost all indicators was the Bull's blood variety, where the height of the rosette was 30.7 cm, the diameter of the rosette was 34.5 cm, and the number of leaves was 29.4 pieces. Among the varieties of chard, the earliest was the Bull's blood variety, and the latest – Mercury and Rubin. At the same time, chard of the Bull's blood and Mercury varieties was noted for the best commercial qualities – 92% and 95%, respectively. According to a study by G.D. Martins *et al.* (2021), comparing the obtained results of biometric indicators of the early spring and summer periods of growing lettuce of various varieties, it was found that the determining factor in productivity during the summer period was the photosynthetic activity of the leaf apparatus, namely, an increase in the length and width of the leaf blade, as well as the number of leaves in the head. During the summer period of lettuce cultivation, all varieties obtained a total yield that exceeded this indicator during the spring planting period by 1.5 t/ha – the Iceberg variety; 1.9 t/ha – Romen; 3.5 t/ha – Lollo Rossa; 2.3 t/ha – Frisse. It should also be noted that all varieties of lettuce have a high marketability relative to chard during the summer planting period, although on average it was 0.6% inferior to the marketability at the spring time of 0.8%.

The biochemical composition of chard leaves is very diverse, but the content of individual components is quite low. The study of the products of primary and secondary metabolism allows determining the required components for the daily diet. In the Bull's blood variety, a high content of dry matter was noted – 94.2%, total sugar – 1.9%, organic acids – 1.2%. In a study by P. Wagacha *et al.* (2022) estimated the dry matter index in the biochemical composition of chard: 11.3-12.5% in leaves, 22-27% in stems. Given the content of essential nutrients, chard contains more than 1% of total sugar, 1.5-1.7% of crude fibre, crude protein – 1.7-1.9%, crude fat up to 0.2%. The content of macro- and microelements in the form of mineral salts of calcium 4.5-5.1 mg/kg, iron 0.2-0.3 mg/kg, potassium – 35-38 mg kg, sodium – 20-22 mg/kg, phosphorus – 4.5-4.8 mg/kg.

Chard is rich in essential amino acids methionine and aspartic acid, as well as a number of organic acids – malic, oxalic and succinic. Based on data from A. Libutti and A.R. Rivelli (2021), rated biochemical analysis of leaves for the content of ascorbic acid, which is an important quality trait for all leafy vegetable crops, in chard its content ranges from 12.0 to 16.0 mg. Chard leaves contain hydroxycortic acids – caffeic, quinic, chlorogenic, which belong to phenolic compounds and are activators of growth processes. Chard contains water-soluble vitamins, represented by thiamine (B_1), riboflavin (B_2), nicotinic acid (PP), rutin (P), folic acid, and ascorbic acid (C). Fat-soluble vitamins in chard are represented by carotene (provitamin A), tocopherol (E), and phylloquinone (K). The study of the biochemical parameters of chard is necessary for breeding work in order to separate promising varieties from those that are developing intensively.

It is necessary to take into account the main energy costs that are associated with the creation of conditions for photosynthesis, in which absorption reactions occur, the conversion of light quanta into organic substances from carbon dioxide and water with the participation of the photosynthetic pigment chlorophyll. Chard leaves are rich in chlorophylls (A and B), carotenoids, as well as various anthocyanin derivatives, tannins, and rutins. M. Iammarino *et al.* (2022) report that pigments are involved in the absorption and transmission of light to reaction centres and have a protective effect against reactive oxygen species produced during photosynthesis. With a significant content of the above pigments, a decrease in the amount of nitrate content is observed. V. Barone *et al.* (2019) argue that the protective properties of green vegetables are primarily associated with the antioxidant properties of their components: vitamins, flavonoids, anthocyanins, polyphenols, a number of trace elements with antioxidant action, such as selenium, zinc, cuprum, ferum. In vegetable growing, several directions are intensively developing, expanding the range of vegetable products, which makes it possible to form a diet with more harmonious and nutritious substances with a high content of antioxidants. According to M. D'Imperio *et al.* (2019), the use of hydroponic systems and natural biostimulants has become a very attractive option for growing green vegetable crops due to the economic value in terms of reducing fertilizer use and maximizing yields.

CONCLUSIONS

In recent years, there has been an active introduction of new and fairly popular varieties of chard in European countries, among green vegetable crops. Based on the results of three-year studies of the adaptive ability for

the period 2020-2022, it can be concluded that the cultivation of chard under greenhouse conditions in the spring turnover from germination to technical ripeness is promising. A detailed study of the products of primary and secondary metabolism makes it possible to determine the compounds that are important for human health, evaluating the indispensability of culture in the daily diet.

Planting seedlings in the spring turnover of closed greenhouses should be carried out in the second half of April according to the 20×15 scheme in closed greenhouses. A wide range of tolerance to growing conditions was noted in the Mercury and Buru varieties; the average range of tolerance is in the varieties Bull's Blood and Bride; a narrow range of tolerance – in the Rubin variety. The duration of the growing season in the spring turnover under the conditions for leaf-type chard was 45-56 days: separately for the Mercury variety – 55 days, the Buru variety – 50 days, the Bull's blood variety – 45 days, the Bride variety – 53 days, the Rubin variety – 55 days. The average yield of sowing chard varieties over a three-year growing period was: for the Mercury variety, 5.27 kg/m^2; Buru – 4.51 kg/m^2; Ruby – 4.86 kg m^2; Bride – 5.09 kg/m^2; Bull's blood – 5.54 kg/m^2. Active accumulation of photosynthesis products in the leaves of most chard varieties took place under the conditions of 2022, especially in the Bull's blood variety – 6.02 kg/m^2. Under saturated light, the content of chlorophylls A and B changed towards equal content regardless of the variety, and total carotene changed depending on the chard variety, mainly with the typical red colour of the stems and leaves of Buru and Bull's blood varieties. In the spring crop rotation, the best properties are shown in red-leaved forms. The conducted accounting of productivity in the cultivation of chard varieties showed a fairly high productivity, while no significant differences due to varietal affiliation were found.

Chard is still little grown on the territory of the Republic of Kazakhstan, but at the same time, the culture has a number of advantages: unpretentious in cultivation, decorative appearance, and most importantly, it has a rich potential for use not only in human nutrition, but also in fodder production. Given the yield data, biometric and biochemical indicators, the studied chard varieties can be recommended for development in agro-formation of all forms of ownership and management in various climatic zones of the Republic of Kazakhstan, with open and closed cultivation.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Адаптаційні здібності сортів мангольду посівного

Алтинай Бейбітівна Ідрісова
Докторант
Казахський національний аграрний дослідницький університет
050010, просп. Абая, 8, м. Алмати, Республіка Казахстан
https://orcid.org/0000-0003-1587-4408

Жангуль Боранкулівна Жумагулова
Кандидат наук, професор
Казахський національний аграрний дослідницький університет
050010, просп. Абая, 8, м. Алмати, Республіка Казахстан
https://orcid.org/0000-0003-3589-8001

Гулнар Амізбаївна Мирзабаєва
Кандидат сільськогосподарських наук, професор
Казахський національний аграрний дослідницький університет
050010, просп. Абая, 8, м. Алмати, Республіка Казахстан
https://orcid.org/0000-0002-3482-3641

Курманкул Тулеутаївна Абаєва
Доктор сільськогосподарських наук, професор
Казахський національний аграрний дослідницький університет
050010, просп. Абая, 8, м. Алмати, Республіка Казахстан
https://orcid.org/0000-0003-3092-5015

Мухіт Дуйсенович Бекбауов
Кандидат сільськогосподарських наук, доцент
Казахський національний аграрний дослідницький університет
050010, просп. Абая, 8, м. Алмати, Республіка Казахстан
https://orcid.org/0000-0001-9161-0792

Анотація. Спосіб вирощування зелених овочевих культур у теплиці, оснащеній сучасними технологіями, дозволяє контролювати вологість, освітленість, температуру, рівень вуглекислого газу, циркуляцію повітря та багато іншого. За допомогою інформаційних та цифрових технологій контролюється швидкість зростання оброблюваних культур, підвищується врожайність, а використання води та ресурсів відбувається більш ефективно, ніж за традиційних методів обробітку. На підставі проведених науково-дослідних робіт у період 2020-2022 рр. за технологією вирощування мангольду посівного в закритих теплицях м. Алмати, Республіки Казахстан, проведено оцінку агробіологічних властивостей, врожайності та адаптивності. Мета статті – вивчення асортименту сортів мангольду посівного та оцінка впливу властивостей ґрунту, температури, освітленості на врожайність, біохімічний склад, біологічну активність. У дослідженнях використовувалися такі методи: лабораторні – які включають моніторинг та оцінку біохімічного складу рослинного матеріалу; біометрії - оцінка параметрів комплексного аналізу середовища та якісних характеристик урожаю; фенології – спостереження за фазами розвитку; статистики – аналіз інформації з оцінки адаптивних можливостей мангольда. Широкий діапазон толерантності до умов вирощування спостерігався у сортів Меркурій та Буру, помірний – у сортів Бича кров та Наречена та більш вузький – у сорту Рубін. У тепличних умовах тривалість вегетації у весняному обороті становила 45-56 днів: сорт Меркурій – 55 днів, Буру – 50 днів, Бича кров – 45 днів, сорт Наречена – 53 дні та Рубін – 55 днів, відповідно. За три роки вирощування середня врожайність мангольду склала сорти Меркурій – 5.27 кг/м^2, Буру – 4.51 кг/м^2, Рубін – 4.86 кг/м^2, Наречена – 5.09 кг/м^2 та Бича кров – 5.54 кг/м^2. У 2022 році у листі більшості сортів мангольда відбувалося активне накопичення фотосинтетичного матеріалу. Зокрема, практичне значення методів вирощування зелених овочів у тепличних умовах, організаційно-економічні процеси тепличного вирощування, вивчення господарсько-біологічних особливостей та врожайності різних сортів мангольду формують стратегію розвитку галузі овочівництва

Ключові слова: сорт; теплиця; біохімічний склад; урожайність; біологічна активність

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 26(7), 129-139

UDC 633.2
DOI: 10.48077/scihor7.2023.129

The effectiveness of forms of mineral fertilisers and productivity of winter wheat on grey-meadow soils of Kyrgyzstan

Musakun Akhmatbekov*
Doctor of Agricultural Sciences, Professor
Kyrgyz National Agrarian University named after K.I. Skryabin
720005, 68 Mederov Str., Bishkek, Republic of Kyrgyzstan
https://orcid.org/0000-0003-1075-3551
Uranbek Shergaziev
Doctor of Agricultural Sciences, Professor
Kyrgyz National Agrarian University named after K.I. Skryabin
720005, 68 Mederov Str., Bishkek, Republic of Kyrgyzstan
https://orcid.org/0000-0002-4203-4060
Kumushbek Mambetov
PhD in Agriculture, Associate Professor
Kyrgyz National Agrarian University named after K.I. Skryabin
720005, 68 Mederov Str., Bishkek, Republic of Kyrgyzstan
https://orcid.org/0000-0003-1867-9560
Sovetbek Mamytkanov
PhD in Agriculture, Associate Professor
Kyrgyz National Agrarian University named after K.I. Skryabin
720005, 68 Mederov Str., Bishkek, Republic of Kyrgyzstan
https://orcid.org/0000-0002-4322-8377
Nurdin Duishembiev
Doctor of Agricultural Sciences, Professor
Kyrgyz National Agrarian University named after K.I. Skryabin
720005, 68 Mederov Str., Bishkek, Republic of Kyrgyzstan
https://orcid.org/0000-0003-3052-0405

Article's History:
Received: 20.04.2023
Revised: 21.06.2023
Accepted: 6.07.2023

Abstract. Fertilisation of winter wheat is necessary to provide the crop with nutrients for optimal growth, development, and formation of the crop. However, the effectiveness of fertilisers may depend on their shape, soil conditions, and climate. The purpose of the study is to examine the effectiveness of using various forms of mineral fertilisers on the formation of productivity of winter wheat on grey-meadow soils of Kyrgyzstan. In 2019-2021, field experiment was conducted in the Educational-experimental Farm of the Kyrgyz National Agrarian University, named after K.I. Skryabin to achieve this

Suggested Citation:
Akhmatbekov, M., Shergaziev, U., Mambetov, K., Mamytkanov, S., & Duishembiev, N. (2023). The effectiveness of forms of mineral fertilisers and productivity of winter wheat on grey-meadow soils of Kyrgyzstan. *Scientific Horizons*, 26(7), 129-139. doi: 10.48077/scihor7.2023.129.

*Corresponding author

goal. As a result of the study, it was identified that the formation of high yields of winter wheat is closely related to the use of nitrogen-containing fertilisers in crop rotation, which contributes to the accumulation of nitrate nitrogen in the soil. The substantial effect of ammonium nitrate and granulated superphosphate on the nitrogen regime of the soil was also noted. The concentration of carbon-ammonium-soluble phosphates is determined by the actions of ammonium sulphate, ammonium nitrate, and all forms of phosphorus fertilisers, but no special changes in the phosphate regime of the soil under the influence of forms of phosphorus fertilisers were identified. However, when using complex fertilisers, a slight accumulation of mobile phosphorus in the soil was noted. The introduction of ammonium nitrate ensures the yield of winter wheat grain at the level of 56 centner/ha, ammonium sulphate – 53.1 centner/ha. granulated superphosphate provided the highest level of winter wheat yield – 55.5 centner/ha and the highest increase in yield against the background of nitrogen-potassium nutrition – 8.7 centner/ha. Therefore, for winter wheat, after rowed precursors, it is preferable to apply ammonium nitrate from nitrogen forms of fertilisers. As an alternative to it – ammonium sulphate or urea, from phosphorus forms of fertilisers – granular superphosphate. The practical importance of the results of the study allows for developing more effective methods of using fertilisers and increasing the productivity of grain crops on grey-meadow soils of Kyrgyzstan and in other regions with similar soil and climatic conditions

Keywords: nitrate nitrogen; carbon-ammonium-soluble phosphorus; crop rotation; agriculture; macronutrients

INTRODUCTION

Winter wheat needs a certain amount of nutrients for normal growth and development. Complex fertilisers should be balanced in nitrogen, phosphorus, potassium, and other necessary trace elements. In addition, in the issue of optimising the nutrition conditions of winter wheat, an important place belongs to the scientifically based choice of the best forms of mineral fertilisers (Wen *et al.,* 2020). The investigation of the effectiveness of forms of mineral fertilisers and their impact on the productivity of winter wheat on grey-meadow soils of Kyrgyzstan is urgent for several reasons. Firstly, grey-earth-meadow soils are one of the main types of soils in Kyrgyzstan, and winter wheat is one of the main agricultural crops. Secondly, the use of mineral fertilisers is one of the main methods of increasing the yield of grain crops, including winter wheat. However, to achieve maximum effect, it is necessary to choose the right forms of fertilisers and their dosage (Aziz *et al.,* 2020).

Scientific studies show that the use of mineral fertilisers can increase the productivity of winter wheat. Thus, V. Vona *et al.* (2022) identified that the use of ammonium nitrate against the background of phosphorus-potassium nutrition led to an increase in the yield of winter wheat grain by 12% compared to using phosphorus-potassium fertilisers alone. According to the study by K. Muydinov *et al.* (2021), conducted in Uzbekistan, the right combination of different types of fertilisers can lead to an even higher yield of winter wheat grain. For example, a study conducted in the Andijan region showed that the use of a complex fertiliser containing nitrogen, phosphorus, and potassium, combined with micro-fertilisers, increased the yield of wheat grain by 50-60% compared to the control without fertilisers.

L. Liang *et al.* (2021) believe that some forms of fertilisers may be more effective on certain types of soils than on others. For example, in areas with low nitrogen content in the soil, the use of ammonium nitrate may be the most effective, while on soils with high nitrogen content, it is better to use more balanced forms of fertilisers, such as carbamide or amophoska. In addition, some forms of fertilisers, such as potash fertilisers, can be especially useful on soils with low potassium content. B.U. Suleymenov *et al.* (2019) also indicate that combining different types of fertilisers can increase soil nutrition and improve its structure, which contributes to better plant growth and development. In addition, according to A.A. Shpedt *et al.* (2021), proper application of mineral fertilisers can increase the quality of winter wheat grain. Mineral fertilisers contain nutrients necessary for the plant, such as nitrogen, phosphorus, potassium, magnesium, and other trace elements that play an important role in the formation and development of wheat grain and can improve its quality.

However, it should be considered that the effectiveness of the use of mineral fertilisers may depend on many factors, such as climatic conditions, soil composition, wheat varieties used, and fertiliser dosages. Therefore, to achieve maximum productivity of winter wheat, it is necessary to consider all these factors. It is important to note that in Kyrgyzstan today the production does not have scientifically based recommendations on the use of more effective forms of nitrogen, phosphorus, and complex fertilisers for winter wheat. In this regard, a comparative assessment of the effect of various forms of mineral fertilisers for winter wheat on grey-meadow soils is quite relevant and has great scientific importance, is of particular interest for practice.

The purpose of the study is to examine the effectiveness of various forms of mineral fertilisers on the formation of winter wheat yields. The following tasks were set and implemented to achieve this goal: analyse the effect of forms of mineral fertilisers on the content of nitrate nitrogen in grey-meadow soil, the effect of forms of phosphorus fertilisers on the content of carbon-ammonium-soluble phosphates in the soil, and examine the productivity of winter wheat grains.

MATERIALS AND METHODS

A field experiment was conducted to examine the effect of mineral fertilisers on the productivity of winter wheat in 2019-2021. The venue is the experimental field of the Educational-experimental Farm of the Kyrgyz National Agrarian University, named after K.I.Skryabin. The study was conducted on grey-earth meadow soils of Kyrgyzstan, which are characterised by an average content of humus, carbonates, and alkalinity. The content of humus in the arable soil layer is 2.3%, the content of gross nitrogen – 0.18%, phosphorus – 0.2, and potassium – 3.05%, mobile forms of phosphorus – 2.8 mg per 100 g of soil, the amount of exchangeable potassium – 52.2 mg per 100 g of soil. The pH value of the soil is 8.5. Since climatic factors are of substantial importance for the formation of the winter wheat harvest, it is necessary to note that the Educational-experimental Farm of the Kyrgyz National Agrarian University, named after K.I. Skryabin is located in the northern part of the republic in the Chui River basin. The zone is irrigated, characterised by a dry continental climate, with hot summers and relatively cold winters. During the study, depending on the prevailing conditions of the year, vegetation irrigation was conducted in the tubing phase and during the grain filling period with an irrigation rate of 700-800 m^3/ha of water per hectare.

The study of the effectiveness of forms of mineral fertilisers for winter wheat was conducted in an eight-field crop rotation with the following alternation of crops: spring barley + alfalfa, winter wheat, corn, winter wheat, corn, winter wheat. The annual fertiliser rate (NPK) was $N_{90}P_{90}K_{30}$. The following forms of fertilisers were examined in the experiment: ammonium nitrate (N_{an}) – 34% N, urea (N_u) – 46% N, ammonium sulphate (N_{as}) – 21.7% N, urea formaldehyde fertiliser (UFF) (N_{UFF}) – 37.7% N, granulated superphosphate (P_{gs}) – 19.5% P_2O_5, double superphosphate (P_{ds}) – 40.2% P_2O_5, fluorinated phosphate (P_{fp}) – 31.5% P_2O_5, ammophos (AM) – 11.2% N, 42.5% P_2O_5, ammonium phosphate (AMP) – 5.6% N, 44% P_2O_5 and potassium chloride K_c – 57% K_2O. Therewith, P15 in rows – control. Fertilisers were applied in fractions: under winter ploughing, in rows during sowing, and in top dressing. The variants of the experiment had a fourfold repetition, the arrangement of plots in the experiment was multi-row-stepped. The total area of the plots – 201.6 m^2 (length – 24 m, width – 8.4 m), accounting – 84 m^2 (length – 20 m, width – 4.2 m).

Nitrate nitrogen was determined in a fresh sample using an ion-selective electrode on an EK-74 device. Mobile phosphorus was analysed in dry samples in a 1% carbon-ammonium extract by the Machigin method in the modification of the Central Agrochemical Agricultural Service Institute on the photo-electrocolorimeter KFK-2 (GOST 26205-91). Harvesting was conducted using a plot-by-plot direct combining with the weighing of bunker grain from the accounting area. In addition, the study analysed the influence of forms of mineral fertilisers on the content of nitrate nitrogen in the soil and the influence of forms of phosphorus fertilisers on the content of carbon-ammonium-soluble phosphates in the soil and examined the productivity of winter wheat, which was formed under the influence of the introduction of mineral fertilisers. All experiments were repeated three times for each variant of the experiment. The obtained results were processed for reliability using the MANOVA multivariate method of variance analysis using Microsoft Excel software and the Statistica 10 software package. Differences in the results obtained are possible at the importance level $P \leqslant 0.05$ according to the Student's criterion.

RESULTS

As a result of the study, it was identified that when using highly soluble forms of nitrogen fertilisers, such as ammonium sulphate, ammonium nitrate, and urea, the content of nitrate nitrogen in the soil increases markedly in relation to the background, although there are no special differences between them (Table 1).

Table 1. *Influence of forms of mineral fertilisers on the content of nitrate nitrogen in the soil, mg per 100 g of soil (average for 2019-2021)*

Variant	Soil layer (cm)	Phases of development of winter wheat					Average for the growing season
		Tillering	Stem elongation	Earing	Milky-waxy ripeness	Full ripeness	
P_{15} in rows (control)	0-25	2.9	2	1.8	1.9	1.3	2
	25-50	2.4	1.5	1.5	0.7	0.6	1.3
	50-75	2.7	1.9	0.4	0.4	0.5	1.2
	75-100	1.7	2.1	0.2	1	0.5	1.1
	average	2.4	1.9	1	1	0.7	1.4
$P_{gs}K_c$ (background)	0-25	3.7	2.9	2	1.2	1.2	2.2
	25-50	2.5	1.4	0.6	0.5	1.4	1.3
	50-75	1.3	1.6	1.1	1.5	0.7	1.3
	75-100	2	1.7	1.3	1.5	0.7	1.4
	average	2.4	1.9	1.3	1.2	1	1.6
Background+N_{an}	0-25	3.7	3.5	2.9	1.3	1.4	2.6
	25-50	3.1	2.9	1.9	1.6	1.8	2

Table 1, Continued

Variant	Soil layer (cm)	Phases of development of winter wheat					Average for the growing season
		Tillering	Stem elongation	Earing	Milky-waxy ripeness	Full ripeness	
Background+N_{an}	50-75	4.5	2.3	2.3	2.5	1.3	2.6
	75-100	3.5	3.2.	2.6	1.6	1	2.3
	average	3.7	3.1	2.5	1.7	1.4	2.4
Background+N_u	0-25	3.5	3	2.8	2.1	2.6	2.8
	25-50	3.3	2.8	1.1	1.1	1.6	1.8
	50-75	2.6	2.9	2.7	0.8	1.1	2
	75-100	2.7	4	1	0.8	0.5	1.8
	average	3.6	3.8	1	1.2	1.5	2.3
Background+N_{as}	0-25	3.9	3.4	2.5	1.7	2.5	2.8
	25-50	2.7	2.4	1.9	1.2	1.1	1.9
	50-75	3.4	3.2.	1.9	1.9	1.3	2.3
	75-100	2.1	3.5	2.8	1.9	1.3	2.3
	average	3	3.1	2.3	1.7	1.6	2.3
Background+N_{UFF}	0-25	4.3	5.1	3.6	3.1	3.1	3.8
	25-50	4	3.9	2.2	2.8	2.1	3
	50-75	3.5	2.7	3	1.5	1.5	2.4
	75-100	2.8	2	2.9	1.7	1.5	2.2
	average	3.7	3.9	2.9	2.3	2.1	2.8
$N_{an}K_c$ (background)	0-25	3.6	3.6	2.3	4.5	4.2	3.6
	25-50	4.4	3.1	2.6	4.7	2.8	3.5
	50-75	5.5	2.1	2.2	4.3	2.4	3.3
	75-100	4.2	4.3	3.9	3.6	1.5	3.5
	average	4.4	3.2.	2.8	4.3	2.7	3.5
Background+P_{gs}	0-25	4	3.8	3.2.	3.2.	3.5	3.5
	25-50	3.5	2.8	2.6	2.8	2.6	2.9
	50-75	3	2.9	2.5	2.5	2.7	2.7
	75-100	2.4	2.2	2.1	2.5	2.5	2.3
	average	3.2.	2.9	2.6	2.8	2.8	2.9
Background+P_{ds}	0-25	3.1	3.8	3	3.7	3.8	3.5
	25-50	3.5	2.3	2	3.5	2.6	2.8
	50-75	2.6	2	1.9	2.4	2.5	2.3
	75-100	2.8	3.4	1.8	2.3	1.8	2.4
	average	3	3.2.	2.2	2.9	2.7	2.7
Background+P_{fp}	0-25	4.5	4	2.8	2.1	2.3	3.1
	25-50	3.5	3.8	2.7	1.8	2.3	3
	50-75	3	2.3	1.7	2.1	2.1	2.3
	75-100	4.1	1.5	1.4	1.8	1.5	2.1
	average	3.9	2.3	2.2	1.9	2.1	2.6
K_c+NP_{am}	0-25	-5.4	4.7	3.4	1.7	2	3.5
	25-50	5.9	3.6	3.7	2.2	2.1	3.5
	50-75	3.5	3.7	2.2	2.1	1.6	2.6
	75-100	3.3	3.3	2.1	2.4	1.7	2.6
	average	4.6	3.8	2.9	2.1	2	3.1
K_c+NP_{amp}	0-25	5.6	5.7	3.4	3.2.	3.6	4.3
	25-50	5.5	4.3	2.5	3.1	2.4	3.6
	50-75	4.1	3.3	1.4	2.6	3.2.	2.9
	75-100	4.1	1.3	1.6	2.7	2.4	2.4
	average	4.9	2.7	2.2	2.8	2.9	3.3

Note: *N_{an} – ammonium nitrate; N_u – urea; N_{as} – ammonium sulphate; UFF – urea-formaldehyde fertiliser; P_{gs} – granulated superphosphate; P_{ds} – double superphosphate; P_{fp} – fluorinated phosphate; AM – ammophos; AMP – ammonium phosphate; K_c – potassium chloride*

Source: *compiled by the authors*

When applying a urea-formaldehyde fertiliser, in which nitrogen is in the form of slightly soluble compounds, a tendency to increase the content of nitrates is observed. This is due to the fact that urea in such fertilisers is presented in the form of poorly soluble compounds that gradually turn into ammonia and other nitrogen compounds, and with their relatively low removal by agricultural crops, which contributes to the accumulation of nitrates in the soil. In the course of investigating the influence of forms of phosphorus fertilisers on the content of nitrate nitrogen in the soil, a rather substantial accumulation of nitrogen-potassium background (without phosphorus) and a decrease in the content of nitrates under the action of phosphorus fertilisers was established. The accumulation of nitrate nitrogen is associated with the weak use of nitrate nitrogen by plants, due to the absence of phosphorus in the composition of the fertiliser. A decrease in the nitrate content under the action of phosphoric fertilisers is associated with an increase in crop yields, as a result of which the absorption of nitrates from the soil increases to create an additional crop. Therewith, there is almost the same content of nitrate nitrogen in the soil, regardless of the forms of phosphorus fertilisers used, and when applying complex fertilisers such as ammophos and ammophosphate, a slight increase was noted. The content of available phosphorus compounds in the soil may depend on the amount and forms of mineral fertilisers used since phosphorus is one of the main elements of plant nutrition and its availability to plants can substantially affect their growth and development. The results obtained indicate that there are no substantial changes in the phosphate regime of the soil under the influence of forms of nitrogen fertilisers. This is due to the fact that nitrogen and phosphorus are different elements of plant nutrition, which have different ways of absorption and movement in the soil (Table 2).

Table 2. *Influence of forms of phosphorus fertilisers on the content of carbon-ammonium-soluble phosphates in the soil, mg per 100 g of soil (average for 2019-2021)*

Variant	Soil layer (cm)	Phases of development of winter wheat					Average for the growing season
		Tillering	Stem elongation	Earing	Milky-waxy ripeness	Full ripeness	
P_{15} in rows (control)	0-25	2.2	2.3	2.9	2.5	1.9	2.4
	25-50	1.1	2	1.6	1.5	1.2	1.5
	50-75	0.7	1.1	0.9	0.9	1	0.9
	75-100	0.7	0.2	0.9	0.7	0.8	0.7
	average	1.2	1.4	1.6	1.4	1.2	1.4
$P_{gs}K_c$ (background)	0-25	2.9	3.8	4	3.2.	3.4	3.5
	25-50	1.6	1.8	1.5	1.7	2	1.7
	50-75	0.8	1.6	0.9	1.2	0.9	1.1
	75-100	0.7	0.8	0.9	0.9	0.8	0.8
	average	1.5	2	1.8	1.8	1.8	1.8
Background+N_{an}	0-25	3.4	3.6	2.6	2.7	2.5	3
	25-50	1.5	2.6	1.6	1.7	1.5	1.8
	50-75	0.7	0.7	1.1	1.2	0.9	0.9
	75-100	0.7	0.6	1	1	0.7	0.8
	average	1.6	1.9	1.6	1.6	1.4	1.6
Background+N_u	0-25	4.2	3.9	3.4	3.8	3.7	3.4
	25-50	1.7	1.3	1.4	1.9	1.8	1.6
	50-75	1	0.9	0.9	1.4	1.2	1.1
	75-100	0.8	0.7	0.9	0.9	0.9	0.8
	average	1.9	1.7	1.6	1.9	1.9	1.7
Background+N_{as}	0-25	3.6	3.4	3.3	3	3.5	3.4
	25-50	2.7	1.5	1.4	1.6	1.8	1.8
	50-75	0.9	1.2	0.9	1.5	0.8	1.1
	75-100	0.8	0.7	1	0.9	0.7	0.8
	average	2	1.7	1.7	1.8	1.7	1.8
Background+N_{UFF}	0-25	3.4	3.8	4.3	3.6	3.6	3.7
	25-50	1.6	2.3	2.3	1.9	2.2	2.1
	50-75	1.1	1.1	1	1.2	1.2	1.1
	75-100	1	0.8	0.9	1	1	0.9
	average	1.8	2	2.1	1.9	2	1.9

Table 2, Continued

Variant	Soil layer (cm)	Phases of development of winter wheat					Average for the growing season
		Tillering	Stem elongation	Earing	Milky-waxy ripeness	Full ripeness	
$N_{an}K_c$ (background)	0-25	2.5	2.8	2.6	2.5	1.8	2
	25-50	1.8	1.7	1.5	1.2	1.2	1.5
	50-75	0.9	1.4	1	0.8	0.9	1
	75-100	0.6	0.7	0.8	0.7	0.8	0.7
	average	1.5	1.9	1.5	1.3	1.2	1.4
Background+P_{gs}	0-25	3.5	4.4	4.3	3.6	2.6	3.7
	25-50	1.2	1.9	1.8	2	1.4	1.7
	50-75	1	1.2	0.9	0.9	0.9	1
	75-100	0.7	1.1	0.8	0.9	0.8	0.9
	average	1.6	2.2	2	1.9	1.4	1.8
Background+P_{ds}	0-25	3.5	4.3	3.6	3.6	3.7	3.7
	25-50	2.2	2.9	2	1.9	2.1	2.2
	50-75	1.1	1.3	1	1.2	1.2	1.2
	75-100	0.8	0.9	0.9	0.9	0.9	0.9
	average	1.9	2.3	1.9	1.9	1.9	2
Background+P_{fp}	0-25	3.7	3.3	3.1	2.3	3.2.	3.1
	25-50	2.5	1.7	1.6	1.2	2.2	1.8
	50-75	0.9	1.1	1	0.8	1	0.9
	75-100	0.8	0.9	0.8	0.8	0.8	0.8
	average	2	1.7	1.6	1.3	1.8	1.7
K_c+NP_{am}	0-25	5.3	5.9	4.7	4.8	5.5	5.2
	25-50	3.3	2.9	2.9	3.7	3.5	3.2.
	50-75	1.9	1.3	1.2	2.2	1	1.5
	75-100	1.1	0.9	0.9	1.2	0.9	1
	average	2.9	2.7	2.4	3	2.7	2.7
K_c+NP_{amp}	0-25	5.1	5.6	4.4	4.5	5	4.8
	25-50	3	2.5	2.7	3.3	3.2.	2.8
	50-75	1.5	1.1	1	2	1	1.3
	75-100	1	0.8	0.9	1.1	0.9	0.9
	average	2.6	2.5	2.2	2.7	2.5	2.5

Note: *N_{an} – ammonium nitrate; N_u – urea; N_{as} – ammonium sulphate; UFF – urea-formaldehyde fertiliser; P_{gs} – granulated superphosphate; P_{ds} – double superphosphate; P_{fp} – fluorinated phosphate; AM – ammophos; AMP – ammonium phosphate; K_c – potassium chloride*

Source: *compiled by the authors*

The influence of forms of nitrogen fertilisers on the phosphate regime of the soil may be insubstantial. However, when using large doses of fertilisers, including both nitrogen and phosphorus, competition may arise between these elements for absorption by plants, which may lead to a change in the phosphate regime of the soil. Therefore, when applying mineral fertilisers, it is necessary to consider not only the amount and forms of fertilisers, but also their ratio, and the properties and condition of the soil. It was also identified that the introduction of phosphorus fertilisers against the background of nitrogen-potassium nutrition is accompanied by an increase in the content of carbon-ammonium-soluble phosphates in the soil. However, there are no substantial changes in the accumulation of mobile phosphorus under the influence of phosphorus-containing fertiliser. Therewith, the least accumulation of mobile phosphorus occurs when using fluorinated phosphate due to the absence of water-soluble phosphorus in its composition. Complex fertilisers have a more substantial effect on the phosphate regime of the soil than fertilisers containing only one element of nutrition. This is due to the fact that when using complex fertilisers containing, for example, both nitrogen and phosphorus, there is a more rational use of these nutrients by plants. Nitrogen and phosphorus

in such fertilisers are in optimal ratios, which helps to improve their interaction in the soil and increase accessibility for plants. In addition, complex fertilisers may contain phosphates that are more readily available to plants than other forms of phosphorus contained, for example, in organic fertilisers. This can lead to an increase in the content of available phosphorus compounds in the soil and improve its availability to plants. The food regime created by the use of various forms of mineral fertilisers affected the productivity of winter wheat. Thus, the unequal effect of the examined forms of nitrogen fertilisers on the yield of winter wheat grain has been established. The most positive effect was provided by water-soluble forms of nitrogen fertilisers, among which ammonium nitrate stands out in value and importance, which provided 56 centner/ha of grain, which is 8.8 centner/ha more than the background. Ammonium sulphate is slightly inferior to it – 53.1 c/ha. The lowest grain yield increases in relation to the phosphorus-potassium background were obtained using urea 4 centner/ha and urea-formaldehyde form of fertiliser – 1.1 centner/ha (Table 3).

Table 3. *Influence of forms of mineral fertilisers on the yield of winter wheat, kg/ha*

Variant	Year			Average for 2019-2021	Increase, centner/ha	
	2019	2020	2021		to control	to the background
P_{15} in rows (control)	37.8	44.6	42.2	41.5	-	-
$P_{gs}K_c$ (background)	39.2	53.5	49.1	47.2	5.7	-
Background+N_{an}	45.7	60.9	61.4	56	14.5	8.8
Background+N_u	41.3	55.6	56.9	51.2	9.7	4
Background+N_{as}	43.5	57.9	58.1	53.1	11.6	5.9
Background+N_{UFF}	40.2	55.1	49.5	48.3	6.8	1.1
$N_{an}K_c$ (background)	38.1	51.3	51.1	46.8	5.3	-
Background+P_{gs}	46.7	58.9	60.9	55.5	14	8.7
Background+P_{ds}	40.1	54.9	54.8	49.9	8.4	3.1
Background+P_{fp}	42.3	57.7	55.9	52	10.5	5.2
K_c+NP_{am}	42.9	56.6	58.5	52.7	11.2	-
K_c+NP_{amp}	39.4	53.1	54.9	49.1	7.6	-
S_x, %	4.1	3.3	3.5			
HCP_{095}, centner/ha	4.7	4.2	4.4			

Note: *N_{an} – ammonium nitrate; N_u – urea; N_{as} – ammonium sulphate; UFF – urea-formaldehyde fertiliser; P_{gs} – granulated superphosphate; P_{ds} – double superphosphate; P_{fp} – fluorinated phosphate; AM – ammophos; AMP – ammonium phosphate; K_c – potassium chloride*
Source: *compiled by the authors*

Among the forms of phosphorus fertilisers, the most preferred position in terms of their effect on the yield of winter wheat grain is granulated superphosphate. Its use as a phosphorus fertiliser provided the highest level of winter wheat yield – 55.5 centner/ha and the highest increase in yield against the background of nitrogen-potassium nutrition – 8.7 centner/ha. The introduction of fluorinated phosphate slightly reduces this indicator to 5.2 c/ha. The weakest effect on the formation of the yield of winter wheat was observed in double superphosphate, with which the increase in crop yield against the background is only 3.1 centner/ha. The predominant effect of granulated superphosphate on the formation of a high yield of winter wheat grain is due to the presence in its composition of a concomitant component of gypsum, which has a reclamation effect on slightly alkaline soils. Thus, when using ammonium nitrate against the background of phosphorus-potassium nutrition, a larger yield of winter wheat grain is formed, and the introduction of granulated superphosphate provides a noticeable increase in the yield of winter wheat compared using other forms of phosphorus fertilisers.

DISCUSSION

The correct dietary regime is one of the important factors affecting the yield of agricultural crops, including winter wheat. Fertilisers are the main source of nutrients for plants, and their proper application helps to provide plants with the necessary nutrients for optimal growth and development. In addition, the nutritional regime of plants affects the presence of easily digestible forms of nitrogen and phosphorus in the soil, since plants absorb nutrients through the roots, and this, in turn, affects the composition of the soil. Plant nutrition conditions include factors such as the level

and chemical composition of the soil, the use of fertilisers, harvesting, and crop rotation. The use of fertilisers containing nitrogen and phosphorus can increase the availability of these elements for plants, whereas harvesting without subsequent fertilisation can lead to soil depletion. Using crop rotations in farming can help preserve soil fertility and increase the availability of nutrients for plants (Chen *et al.,* 2019).

Studies by S. Tandy *et al.* (2021) and M.N. Ashraf *et al.* (2021) show that the application of only nitrogen and potash fertilisers without phosphorus can lead to the accumulation of nitrate nitrogen in the soil. This is due to the fact that potash fertilisers can increase the assimilation of nitrate nitrogen by plants, and nitrogen fertilisers can stimulate its accumulation in the soil. Therewith, phosphorus fertilisers can improve the absorption of other forms of nitrogen by plants, such as ammonium and amide, which do not accumulate in the soil in such large quantities as nitrate. Notably, the accumulation of nitrate nitrogen in the soil may be undesirable, as this can lead to contamination of groundwater and aquatic ecosystems and a decrease in the quality of agricultural products. Therefore, it is important to combine fertilisers correctly, consider the needs of crops and soil characteristics to achieve optimal results in agriculture. All this actualises the solution of the problem of nitrate accumulation in the soil in the context of modern agriculture.

K. Ibrahim *et al.* (2021) in their paper note that the introduction of phosphorus fertilisers against the background of nitrogen-potassium nutrition can reduce the content of carbon-ammonium-soluble phosphates in the soil and increase the availability of phosphorus for plants. In addition, N. Kokovic *et al.* (2021) believe that the use of fluorinated phosphate, which does not contain water-soluble phosphorus, can lead to the least accumulation of mobile phosphorus in the soil. Water-soluble phosphorus can quickly pass into the soil solution and become available to plants, but it can also be easily washed out of the soil by rainwater, which can lead to environmental pollution. Thus, the right combination of fertilisers, considering the needs of plants and soil characteristics, can substantially increase the productivity of crops and reduce fertiliser costs.

According to Q. Wu *et al.* (2020), different forms of fertilisers may have different effectiveness on different types of soil. For example, nitrogen fertilisers can be represented in various forms, such as ammonium nitrate, urea, or ammonium salts. Some of these forms may dissolve better in acidic soils, while others may be more effective on alkaline soils. In addition, low availability of phosphorus is often observed in acidic soils, which can reduce the effectiveness of the use of phosphorus fertilisers. Therefore, to ensure the best efficiency of the use of fertilisers, it is necessary to consider the type of soil and its chemical composition in each specific area, and recommendations for the use of fertilisers. This will help to use resources as efficiently as possible and achieve high crop yields with minimal environmental impact.

A study by M. Berca *et al.* (2017) shows that the use of ammophos can have a positive effect on the yield of winter wheat grain, but it will not necessarily have advantages over a mixture of fertilisers. Thus, the use of ammophos at a dosage of 120 kg/ha affected the increase in winter wheat grain yield by 7.6%, compared with the control group without fertilisers. However, a mixture of fertilisers containing nitrogen, phosphorus, and potassium, at a dosage of 100 kg/ha, also gave an increase in grain yield by 7.5%, which indicates that this fertiliser can be no less effective. In addition, according to J. Singh *et al.* (2013), the use of ammonium nitrate in combination with phosphorus-potassium fertiliser can lead to the formation of a higher yield of winter wheat grain than when using only phosphorus-potassium fertilisers, which was also identified in the course of the study.

Similar results were obtained in a study conducted by L. Prysiazhniuk *et al.* (2023), according to which, the use of ammonium nitrate against the background of phosphorus-potassium nutrition led to an increase in the yield of winter wheat grain by 5-10% compared to only using phosphorus-potassium fertilisers. Therewith, not only the quantity of the crop increases but also the quality of the grain – its size, weight, and protein content. M.B.H. Ros *et al.* (2020) also claim that ammonium nitrate is a nitrogen fertiliser that promotes accelerated plant growth and increases their yield. In addition, nitrogen is necessary for the formation of chlorophyll, which plays a key role in photosynthesis, and for the formation of proteins, which are an important element of grain. Granulated superphosphate has a substantial effect on the formation of winter wheat grain yield. It contains 19.5% of phosphoric acid, which is one of the most important macronutrients for plants, especially for winter wheat. Phosphorus contributes to the development of the root system, strengthening of the stem, grain formation, and improvement of its quality (Keller *et al.,* 2021). In addition, granulated superphosphate has good solubility, which allows it to quickly enter the plant and have a positive effect on its development. Due to the granular form of the fertiliser, its application is simplified, since it is evenly distributed in the soil, which ensures maximum efficiency (De Oliveira *et al.,* 2020).

The results obtained correspond to those of a study by H.S. Jat *et al.* (2019), indicating that the use of granulated superphosphate can have a positive effect on the formation of a high yield of winter wheat grain, contributing to an increase in yield by 5-15%, depending on the dose. In addition, a study conducted in the fields of Kazakhstan showed that the use of granulated superphosphate at a dosage of 30 kg/ha gave an increase in the yield of winter wheat grain by 8.6%, compared with the control variant without fertilisers (Buntic *et al.,*

2019). Similar results were obtained in studies conducted in Ukraine, according to which, the use of granulated superphosphate at a dosage of 60 kg/ha gave an increase in the yield of winter wheat grain by 13%, compared with the control option without fertilisers (Solodushko *et al.,* 2021).

Considering the mentioned studies, and the results obtained in this one, it can be argued that the use of complex fertilisers containing all three main macronutrients – nitrogen, phosphorus, and potassium, provides the greatest effectiveness of the impact on winter wheat and increases its yield. However, it is necessary to consider the characteristics of the soil and follow the recommendations on the dosage and method of fertilisation to minimise the negative impact on the environment.

CONCLUSIONS

Obtaining a high yield of winter wheat is closely related to the use of nitrogen-containing fertilisers in crop rotation, which contributes to the accumulation of nitrate nitrogen in the soil. The highest concentration of nitrate nitrogen under winter wheat was noted when using a urea-formaldehyde form of fertiliser, with a decrease in its content when using ammonium nitrate, urea, and ammonium sulphate. No substantial changes in the nitrate content under the influence of phosphorus-containing mineral fertilisers have been established. It is also important to note that complex fertilisers, compared with a mixture of separate fertilisers, slightly increase the content of nitrate nitrogen in the soil. In addition, the accumulation of carbon-ammonium-soluble phosphates in the soil increases under the influence of forms of phosphorus fertilisers, but no substantial differences in the content of mobile phosphorus in the soil were identified. However, the tendency of increasing the accumulation of carbon-ammonium-soluble phosphates during the application of complex fertilisers was established.

Thus, it can be stated that it is preferable to use ammonium nitrate for winter wheat in crop rotation after rowed precursors from nitrogen forms of fertilisers. As an alternative, ammonium sulphate can also be used, and in extreme cases, urea. The use of the urea-formaldehyde form of fertilisers in the conditions of grey-meadow soils is ineffective. The introduction of granular superphosphate is more effective among the forms of phosphorus fertilisers. The action of fluorinated phosphate and especially double superphosphate is less effective, but in the absence of superphosphate, they can also be used for application under winter wheat. Among the complex fertilisers, ammophos contributes to the formation of a higher yield of winter wheat than ammonium phosphate. It was also identified that ammonium nitrate ensured the yield of winter wheat grain at the level of 56 centner/ha, ammonium sulphate – 53.1 centner/ha. The use of granulated superphosphate as a phosphorus fertiliser provided the highest level of winter wheat yield – 55.5 centner/ha and the highest increase in yield against the background of nitrogen-potassium nutrition – 8.7 centner/ha. The weakest effect on the yield of winter wheat was observed in double superphosphate. Consequently, on the grey-earth-meadow soils of Kyrgyzstan, with the correct selection of forms of mineral fertilisers in the crop rotation after corn, it is possible to obtain a harvest of winter wheat grain of more than 55 centner/ha.

The practical importance of the research results lies in the possibility of developing more effective methods of using fertilisers and increasing the yield of grain crops on grey-meadow soils of Kyrgyzstan and in other regions with similar soil and climatic conditions. The prospect of further research is to examine the economic efficiency of using various forms of mineral fertilisers, which can help agricultural producers make more informed decisions about which fertilisers to use and in what doses.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Ефективність форм мінеральних добрив і продуктивність озимої пшениці на сіроземно-лучних ґрунтах Киргизстану

Мусакун Ахматбекович Ахматбеков
Доктор сільськогосподарських наук, професор
Киргизький національний аграрний університет імені К.І. Скрябіна
720005, вул. Медерова, 68, м. Бішкек, Киргизстан
https://orcid.org/0000-0003-1075-3551

Уранбек Адійович Шергазієв
Доктор сільськогосподарських наук, професор
Киргизький національний аграрний університет імені К.І. Скрябіна
720005, вул. Медерова, 68, м. Бішкек, Киргизстан
https://orcid.org/0000-0002-4203-4060

Кумушбек Бекітаєвич Мамбетов
Кандидат сільськогосподарських наук, доцент
Киргизький національний аграрний університет імені К.І. Скрябіна
720005, вул. Медерова, 68, м. Бішкек, Киргизстан
https://orcid.org/0000-0003-1867-9560

Совєтбек Асангазійович Мамитканов
Кандидат сільськогосподарських наук, доцент
Киргизький національний аграрний університет імені К.І. Скрябіна
720005, вул. Медерова, 68, м. Бішкек, Киргизстан
https://orcid.org/0000-0002-4322-8377

Нурдін Дуйшембійович Дуйшембієв
Доктор сільськогосподарських наук, професор
Киргизький національний аграрний університет імені К.І. Скрябіна
720005, вул. Медерова, 68, м. Бішкек, Киргизстан
https://orcid.org/0000-0003-3052-0405

Анотація. Удобрення озимої пшениці необхідне, щоб забезпечити культуру поживними речовинами для оптимального росту, розвитку та формування врожаю. Однак, ефективність добрив може залежати від їхньої форми, а також від ґрунтових умов і клімату. Мета роботи – вивчити ефективність застосування різних форм мінеральних добрив на формування продуктивності пшениці озимої на сіроземно-лучних ґрунтах Киргизстану. Для досягнення поставленої мети у 2019-2021 рр. проводили польовий дослід у Навчально-дослідному господарстві Киргизького національного аграрного університету ім. К.І. Скрябіна. У результаті дослідження встановлено, що формування високої врожайності пшениці озимої тісно пов'язане із застосуванням у сівозміні азотовмісних добрив, що сприяє накопиченню в ґрунті нітратного азоту. Також відмічено суттєву дію на азотний режим ґрунту аміачної селітри та суперфосфату простого гранульованого. Концентрація вуглеамонійрозчинних фосфатів визначається діями сульфату амонію, аміачної селітри та всіх форм фосфорних добрив, але особливих змін у фосфатному режимі ґрунту під впливом форм фосфорних добрив не виявлено. Однак за використання складних добрив відзначено незначне накопичення рухомого фосфору в ґрунті. Внесення аміачної селітри забезпечує врожайність зерна озимої пшениці на рівні 56 ц/га, сульфату амонію – 53,1 ц/га. Суперфосфат простий гранульований забезпечив найвищий рівень урожаю озимої пшениці – 55,5 ц/га та найвищу прибавку до врожаю на фоні азотно-калійного живлення – 8,7 ц/га. Отже, під озиму пшеницю після просапних попередників з азотних форм добрив краще вносити аміачну селітру, а як її альтернативу – сульфат амонію або сечовину, з фосфорних форм добрив – суперфосфат простий гранульований. Практична значущість результатів дослідження дає можливість розробити більш ефективні методи використання добрив і збільшення продуктивності зернових культур на сіроземно-лучних ґрунтах Киргизстану, а також в інших регіонах зі схожими ґрунтово-кліматичними умовами

Ключові слова: нітратний азот; вуглеамонійрозчинний фосфор; сівозміна; сільське господарство; макроелементи

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 26(7), 140-148

UDC 631.33:633.15
DOI: 10.48077/scihor7.2023.140

System of pre-sowing seed inoculation

Mykola Shelest
PhD Student
Sumy National Agrarian University
40021, 160 H. Kondratieva Str., Sumy, Ukraine
https://orcid.org/0000-0001-5722-8944
Alex Kalnaguz
Senior Lecturer
Sumy National Agrarian University
40021, 160 H. Kondratieva Str., Sumy, Ukraine
https://orcid.org/0000-0003-1710-8416
Oksana Datsko
PhD Student
Sumy National Agrarian University
40021, 160 H. Kondratieva Str., Sumy, Ukraine
http://orcid.org/0000-0001-9610-3087
Elina Zakharchenko*
PhD in Agricultural Sciences, Associate Professor
Sumy National Agrarian University
40021, 160 H. Kondratieva Str., Sumy, Ukraine
http://orcid.org/0000-0002-9291-3389
Vladyslav Zubko
Doctor of Technical Sciences, Professor
Sumy National Agrarian University
40021, 160 H. Kondratieva Str., Sumy, Ukraine
https://orcid.org/0000-0002-2426-2772

Article's History:
Received: 1.05.2023
Revised: 28.06.2023
Accepted: 12.07.2023

Abstract. Pre-sowing inoculation of agricultural crops increases the parameters that affect the yield and quality of the crop, which has been proven by many Ukrainian and foreign researchers. The purpose of the study was to set the operating parameters of the injectors at different pressures, which allowed calculating the rate of discharge of the working solution during sowing to create a system of pre-sowing inoculation, which will simplify the process of seed treatment and increase the energy efficiency of farms. Methods of system and structural analysis, mathematical statistics, abstraction, and mathematical modelling based on the Euler-Lagrange equation, and using the foundations of theoretical mechanics, physics and machine theory were used for

Suggested Citation:
Shelest, M., Kalnaguz, A., Datsko, O., Zakharchenko, E., & Zubko, V. (2023). System of pre-sowing seed inoculation. *Scientific Horizons*, 26(7), 140-148. doi: 10.48077/scihor7.2023.140.

*Corresponding author

experimental research. The planning of the experiment met the current standards, and computer graphics systems and Microsoft Excel software suite were used for statistical data processing. Based on the conducted studies, the amount of liquid that one nozzle can pass in 1 min at pressures of 300, 400, and 500 kPA was determined. It was found that the lowest result was shown by a nozzle with a diameter of 0.1 mm with a pressure of 300 kPA – 10.493 ml/min, and the highest – a nozzle with a diameter of 0.8 mm and a pressure of 500 kPA – 146.379 ml/min. At the same time, injectors with a diameter of 0.4-0.6 mm used almost the same amount of liquid at pressures of 300 and 500 kPA. The amount of liquid that can be poured per 1 ha using a six-row seeding machine with a working width of 4.2 m per sowing unit of corn was calculated. The obtained data can be used to improve any systems that use similar nozzles, such as calculating the rate of discharge of agricultural sprayers or systems that allow cooling pig farms during the summer period

Keywords: operation of the sowing complex; nozzle; yield; pressure; spout rate; seed coating; biologics; fertilisers; microorganisms; sowing quality

INTRODUCTION

The issue of seed inoculation is quite relevant today. Humanity is trying to improve the global environment, and therefore, reduce the use of chemicals in agriculture. Inoculants, as a means to increase yields and improve the quality of plant products, have proven themselves quite well. For example, in studies on the effect of an inoculant (strain *Rhizobium*) on chickpea plants under salinity conditions, not only an increase in yield was recorded, but also an increase in the protein and oil content in seeds (Khaitov *et al.,* 2020). An increase in protein content was recorded with the use of Microgumin, Diazophyte, and mineral fertilisers in studies of oat cultivation (*Avena nuda L.* and *Avena sativa L.*) (Ilchenko *et al.,* 2019). And during the investigation of the effects of four strains of *Bacillus spp.* on corn plants under water stress, an increase in the mass of raw and dry matter, the length of plants, and the amount of photosynthetic pigments in them was observed (Azeem *et al.,* 2022). Therefore, against the background of complicated opportunities for the supply of fertilisers from abroad and the need to provide crops with the necessary substances, inoculants or other biologics that are recommended to be used during sowing are a very promising due to their relatively low price, environmental friendliness, positive effect on crop yields, and most importantly – the ability of domestic producers to provide farmers with this product (Polischuk *et al.,* 2023).

The advantages of settling microorganisms on the seed surface (inoculation) before sowing have been proven by many researchers (Stassinos *et al.,* 2021; Datsko, 2021). The history of their use began in 1896, when the first patent for an inoculant was registered in the United States (Santos *et al.,* 2019). Inoculation of seed material allows populating the necessary microorganisms in the rhizosphere of agricultural crops for better interaction and increase plant productivity (Sandini *et al.,* 2019). Mostly, when it comes to inoculation procedure, most suggest that it applies only to legumes, however, this is not a fair expression. Studies using inoculants have also been conducted for crops such as corn (Stoffel *et al.,* 2020), wheat (Erdemci, 2021), rice (Guimarães *et al.,* 2020; Singh *et al.,* 2020), rapeseed (Premachandra *et al.*, 2020) etc.

Inoculation in production is mainly carried out with the help of seed treatment machines and in addition to or simultaneously with seed treatment. However, the method of liquid inoculation has significant disadvantages, which can lead to an increase in the cost of production or to the death of microorganisms contained in the inoculant. The first and most important of them is that the operation with a liquid inoculant is quite a time-consuming process, since it is usually recommended to apply microorganisms immediately before sowing, which requires the additional use of the necessary equipment and people in a short time. Second, direct exposure to sunlight on already treated seed material can lead to the death of beneficial microorganisms (Ushkarenko *et al.,* 2016). The reason for this harmful effect of solar radiation on bacterial cells is ultraviolet light, which has a bactericidal effect (Bilokonska, 2018).

Therefore, researchers of Sumy National Agrarian University decided to develop and implement a system that will simplify the inoculation process and conduct it during corn sowing. Since the methods used by agricultural producers for inoculation are outdated and energy-consuming, the purpose of this study was to obtain data that will allow assessing which nozzles should be used to create a seed inoculation system that can be installed in any sowing complex.

MATERIALS AND METHODS

Structure of the test system for determining required nozzle diameter and operating pressure. Since the system is designed and manufactured from scratch, it became necessary to investigate the properties of components and select the necessary parameters. To begin with, the pressure needed to be created in the system and the diameter of the nozzles to be used were considered. To do this, the volume of liquid that the nozzle can pass through with a certain pressure was measured for one minute for each of the options in triple repetition.

Laboratory balances (Radwag, WLC 0.2/C/1, Poland) were used to accurately determine the weight of liquid. The pressure was created using a high-pressure diaphragm pump (Good PUMPs, 12V, 6A, 72W, China). The low-pressure mist-forming TW6010 ….TW6080 with a diameter of 0.1; 0.2…..0.8 mm were chosen as nozzles (Fig. 1).

Figure 1. *Low-pressure mist forming nozzles TW60*

A pressure gauge, quick-release connections, hoses, clamps, and a digital pressure sensor (Ebowan DC 5 V G1/4, 12 MPA, China) were also used to create the test sample, the connection diagram is shown in Figure 2.

Figure 2. *Connection diagram of devices for determining the required nozzle diameter and operating pressure for creating a stand, where 1 – tank; 2 – pressure gauge; 3 – water pump; 4 – pressure sensor; 5 – actuator; 6 – nozzle*

Based on the requirements of inoculant manufacturers, a darkened tank was used to minimise the contact of microorganisms with ultraviolet rays. The liquid filled into the tank is sucked in by a pump that pumps pressure into the main line, which contains a pressure gauge for visual monitoring and a digital pressure gauge for maintaining pressure. An actuator valve regulates the period of use of the nozzle (Shelest *et al.,* 2022).

After conducting the study, the appropriate equation was used to determine the actual amount of liquid that can be poured per 1 ha by a six-row row seeding machine with a working width of 4.2 m. (Bosoy *et al.,* 1980):

$$Q = \frac{600q \times n}{L \times V}, \quad (1)$$

where Q – actual working fluid discharge, l/ha; 600 – coefficient; n – number of sprayers; q – liquid flow rate through one sprayer, l/min.; L – working width of the unit, m; V – actual velocity, km/h.

For statistical processing of the spray fluid flow rate, the root-mean-square deviation (2) and the coefficient of variation (3) were determined:

$$\sigma = \sqrt{\frac{(q_{1e}-\overline{q})^2+(q_{2e}-\overline{q})^2+\ldots..+(q_{ne}-\overline{q})^2}{n}}; \quad (2)$$

where q_{1e}, q_{2e}….q_{ne} – amount of liquid consumed by the sprayer in 1 minute, g; $\overline{q}$ – arithmetic mean; n – number of experiments.

$$\overline{q} = \frac{q_{1e}+q_{2e}+\ldots.q_{ne}}{n}$$

The coefficient of variation was determined by the equation:

$$V = \frac{\sigma}{\overline{q}} \cdot 100. \quad (3)$$

To evaluate the results of the study of nozzles of different sizes when using a pressure of 300-500 kPA, a two-fold variance analysis with repetitions was conducted in MS Excel.

As a liquid, water-based injectors were first tested, and then Leanum biologic preparation was used, which contains effective microorganisms and organic matter, and is approved for use by "Organic Standard". It is evident

that the density of different liquid fertilisers/biologics may differ, different volumes of working solution can be used in different dosages (200-300 l/ha), depending on the manufacturer's recommendations.

RESULTS AND DISCUSSION

Investigation of the amount of liquid that the nozzles can pass in 1 min. Studies were conducted on nozzles of different diameters and at different pressures of liquid supply to them for the same period of time. Analysing the data in Table 1, the dependence of the volume of liquid through the nozzles on the diameter of the hole is observed: with an increase in the nozzle diameter from 0.1 mm to 0.2 mm at a constant pressure of 300 kPA, the weight of liquid that was sprayed in 1 min increased from 10.373 g to 13.445 g, which is 22.2%.

Table 1. *Result of the study of nozzles of different sizes at a pressure of 300 kPA*

Nozzle size, mm	Experiment number						$\bar{q}$, g	σ, g	V_σ, %
	1	2	3	4	5	6			
0.1	10.373	10.609	10.511	10.456	10.305	10.702	10.493	0.13	1.3
0.2	13.445	13.56	13.472	13.601	13.27	13.602	13.492	0.12	0.9
0.3	35.69	35.822	35.973	35.599	35.984	35.902	35.828	0.14	0.4
0.4	52.7	52.329	52.629	52.485	52.502	52.688	52.556	0.13	0.2
0.5	65.426	65.429	65.408	65.281	65.29	65.692	65.421	0.14	0.2
0.6	81.03	81.243	81.207	81.401	81.011	81.102	81.166	0.14	0.2
0.7	92.385	92.729	92.921	92.393	92.829	92.809	92.678	0.21	0.2
0.8	114.926	115.06	115.203	115.182	114.903	115.102	115.063	0.12	0.1

Source: *obtained by the authors*

Starting from the nozzle diameter of 0.3 mm, the weight of the liquid relative to the original diameter increased by almost 3.5 times. As the injector nozzle diameter increased from 0.3 mm to 0.8 mm, the increase in the volume of liquid pouring through the nozzles significantly increased from the minimum water mass of 35.69 g to 114.926 g, which is an average increase of 69%. During statistical data processing, the root-mean-square deviation was in the range of 0.12-0.14 g, with the maximum value for the nozzle diameter of 0.7 mm – 0.21 g. The coefficient of variation decreased and corresponded to an increase in the nozzle diameter and was a minimum value of 0.1% for 0.8 mm and a maximum value of 1.3% for 0.1 mm.

When analysing the weight values of the spray liquid at a constant pressure of 400 kPA in 1 minute (Table 2), the lowest value of the weight of liquid through the nozzles of low-pressure mist-forming nozzles was 0.1 mm – 12.146 g and 0.2 mm – 15.101 g. When the diameter of the mist-forming nozzles increases from 0.3 mm to 0.7 mm, respectively, the liquid flow rate increases from 40.907 g/min up to 97.443 g/min. The highest consumption of sprayed liquid is 142.209 g/min with a nozzle diameter of 0.8 mm, because the increase relative to 0.7 mm is the largest – 45 g/min. When evaluating the data in Table 2, a root-mean-square deviation was determined with a minimum value of 0.05 g for a nozzle diameter of 0.8 mm and a maximum value of 0.32 g for 0.5 mm. The coefficient of variation was reduced from 1% for nozzle diameters of 0.1 mm and 0.2 mm to 0% for nozzle diameters of 0.8 mm.

Table 2. *Result of the study of nozzles of different sizes at a pressure of 400 kPA*

Nozzle size, mm	Experiment number						$\bar{q}$, g	σ, g	V_σ, %
	1	2	3	4	5	6			
0.1	12.509	12.183	12.146	12.231	12.403	12.307	12.297	0.13	1.0
0.2	15.576	15.32	15.101	15.297	15.477	15.218	15.332	0.16	1.0
0.3	40.428	40.869	40.695	40.641	40.445	40.907	40.664	0.19	0.5
0.4	57.871	58.225	58.184	57.698	58.308	58.274	58.093	0.23	0.4
0.5	72.606	73.005	72.504	72.695	73.105	72.315	72.705	0.27	0.4
0.6	92.746	91.993	92.328	92.629	91.899	92.537	92.355	0.32	0.3
0.7	97.41	97.417	97.503	97.269	97.381	97.68	97.443	0.13	0.1
0.8	142.202	142.073	142.192	142.152	142.102	142.209	142.155	0.05	0

Source: *obtained by the authors*

At a constant pressure of 500 kPA, the volume of sprayed liquid increases accordingly with an increase in the diameter of fine nozzles from 0.1 mm to 0.8 mm: from a minimum value of 13.696 g/min at 0.1 mm to a maximum of 146.827 g/min at 0.8 mm (Table 3). From the nozzle diameter of 0.3 mm, there is an increase in the flow rate of the sprayed liquid relative to the diameter of 0.1 mm by almost 3.5 times.

From the statistical analysis of the table data, the minimum root-mean-square deviation is 0.19 g from the arithmetic mean of 17.094 g for a nozzle diameter of 0.2 mm, and the maximum is 1.1 g from the arithmetic mean of 64.388 g for a diameter of 0.4 mm. The coefficient of variation increased from 0.2% for 0.7 mm and 0.8 mm nozzle diameters to 1.7% for a nozzle diameter of 0.4 mm.

Table 3. *Result of the study of nozzles of different sizes at a pressure of 500 kPA*

Nozzle size, mm	Experiment number						$\bar{q}$, g	σ, g	V_σ, %
	1	2	3	4	5	6			
0.1	13.947	13.836	13.811	13.748	13.696	13.947	13.831	0.09	0.7
0.2	17.181	16.758	17.399	17.123	16.992	17.109	17.094	0.19	1.1.
0.3	44.764	45.088	44.68	45.141	44.592	44.799	44.844	0.20	0.5
0.4	62.576	65.427	65.765	63.599	64.966	63.997	64.388	1.11	1.7
0.5	81.557	80.993	81.648	81.312	80.898	81.203	81.269	0.27	0.3
0.6	98.416	98.336	98.432	97.892	98.598	98.692	98.394	0.25	0.3
0.7	113.408	113.499	113.509	113.101	113.791	113.521	113.472	0.20	0.2
0.8	146.375	146.372	146.394	146.102	146.827	146.201	146.379	0.23	0.2

Source: *obtained by the authors*

By increasing the fluid supply pressure to the 0.1 mm diameter nozzle from 300 kPa to 500 kPa, the fluid output increased by 32%. On average, at a pressure of 500 kPA, all injectors delivered almost 580 g/min, which is 9.16% more than at a pressure of 400 kPA, and 24.21% more than at a pressure of 300 kPA.

Calculation of the amount of liquid per 1 ha. The flow rate of the working fluid of the nozzle with a diameter of 0.1 mm at different pressures ensures the discharge of liquid in the range of 1.12-1.48 l/ha (Fig. 3), and the nozzle with a diameter of 0.2 mm – 1.44-1.83 l/ha, while the difference between the values of the 0.1 mm nozzle with a pressure of 500 kPA and the 0.2 mm nozzle at a pressure of 300 kPA is only 2.7%, which is not a critical deviation, but when working in the field to save energy resources, it is undoubtedly better to use a nozzle with a diameter of 0.2 mm and a pressure of 300 kPA. A similar pattern can be observed in 0.4 and 0.5 mm nozzles, where the difference between the values at a pressure of 500 and 300 kPA is 1.7%. A similar pattern is observed between the 0.5 and 0.6 mm injectors, the difference between the indicators is also not significant and amounts to 0.2%. At the same time, there is no similar trend between 0.6 and 0.7 mm injectors and the same pressure, but this phenomenon again becomes true for 0.7 and 0.8 mm injectors, while the difference between the liquid output at a pressure of 500 and 300 kPA is 1.3%.

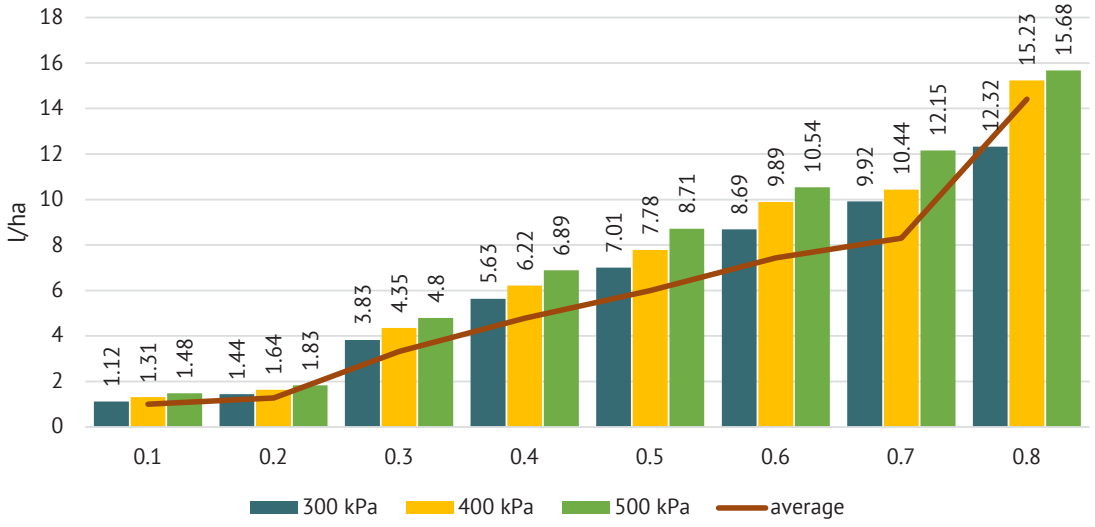

Figure 3. *Flow rates through the TW6010....TW6080 nozzles at different pressure values*

Therefore, the diagram shows that injectors with a diameter of 0.1 and 0.2 mm provide extremely low use of the working solution per hectare, which casts doubt on the effectiveness of their use. At the same time, nozzles with a diameter of 0.3 to 0.8 mm have the potential for use in the designed pre-sowing inoculation system.

Other researchers have also created a sowing complex that can carry out seed inoculation during corn sowing (Dražić, 2017). However, their research is somewhat inconsistent with the subject matter and the need for creating a seed inoculation system. For example, the paper by Klaedtke *et al.* (2022) contains information about the amount of liquid passed by nozzles per minute under different pressures, but they do not contain specifics about the diameter of the injectors. Pathan *et al.* (2019) provide information about working under different pressures for three nozzles (diameter 13.1; 16.2; 19.3 mm), however, these nozzles have a fairly high output of liquid, while this study is based on saving water and creating a mist for more uniform treatment of seeds with a working solution. A similar experiment was conducted by Han *et al.* (2020), however, using a different type of nozzle. Wang *et al.* (2020) investigated the efficiency of using larger nozzles and higher pressures (from 1 to 8 mPA). However, according to the estimates, a pressure greater than 500 kPA is not appropriate for a mobile inoculation system, as it requires high energy consumption.

In the literature, attention is drawn to the fact that seed treatment with biologics is more effective than their foliar application (Barbosa *et al.,* 2022), and the effect is noticeable in the growth of the root system, the concentration of nutrients in the leaf-stem mass, and grain, which ultimately affected the yield. But biologics can have one or more strains of microorganisms, and depending on weather and soil conditions, their effectiveness may decrease or not appear at all in temperate climates (Reis *et al.*,2022). However, the application of biologics and fertilisers in liquid form is more effective than in the form of powder and granules, and the most important thing at the beginning is uniform application to the seed and good adhesion, since the seeds of different agricultural plants have different shapes, structures, sizes, and germination rates (Paravar *et al.,* 2022; Veremeenko *et al.,* 2023). That is, considering seed treatment with biologics only in organic farming, then the purpose of this event is to directly affect the seed and the plant will better resist abiotic and biotic stresses through rhizobiome (Kharchenko *et al.,* 2022; Orozco-Mosqueda, 2022). By using xerotolerant microorganisms in the seed coating, it is possible to promote better plant development in conditions of prolonged moisture limit (Romao *et al.,* 2022).

Thus, data on the amount of solution pouring through different nozzles were obtained in other papers, but the effectiveness of using different pressures and diameters of nozzles, and the density of fertiliser liquids and pesticides was not fully investigated. The development of complexes for inoculation with minimal moisture and energy consumption is relevant and requires further study.

CONCLUSIONS

Based on the data obtained, it can be concluded that the smallest liquid output per minute in a nozzle with a diameter of 0.1 mm with a pressure of 300 kPA is 1.247 l/ha, while the largest output in nozzles of 0.8 mm with a pressure of 500 kPA is 15.683 l/ha. The range of fluctuations in these values is quite high, so further, more in-depth studies of injectors with a diameter of 0.3-0.6 mm are needed. Nozzles with a diameter of 0.1 and 0.2 are not suitable for further research, as they pass too little liquid from 1.127 to 1.831 l/min at different pressures, while nozzles with a diameter of 0.7-0.8 are rejected because they have too unstable indicators. Moreover, an interesting pattern was noticed in the 0.4, 0.5, and 0.6 nozzles at a pressure of 500 and 300 kPA: the amount of liquid that they can pour per 1 ha is almost similar and the difference between these values does not exceed 2.7% (and some even less), which is insignificant. These circumstances suggest the feasibility of using a nozzle with a smaller diameter and higher pressure in the inoculation system, or with a larger nozzle diameter and lower pressure, which would directly affect the amount of energy consumed by the tractor during the use of this system.

ACKNOWLEDGEMENTS

The authors are thankful to the Czech government support provided by the Ministry of Foreign Affairs of the Czech Republic, which allowed this scientific cooperation to start within the project "Interuniversity cooperation as a tool for enhancement of quality of selected universities in Ukraine".

CONFLICT OF INTEREST

The authors declare no conflict of interests.

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Система припосівної інокуляції насіння

Микола Сергійович Шелест
Аспірант
Сумський Національний Аграрний Університет
40021, вул. Герасима Кондратьєва, 160, м. Суми, Україна
https://orcid.org/0000-0001-5722-8944

Олексій Миколайович Калнагуз
Старший викладач
Сумський Національний Аграрний Університет
40021, вул. Герасима Кондратьєва, 160, м. Суми, Україна
https://orcid.org/0000-0003-1710-8416

Оксана Миколаївна Дацько
Аспірант
Сумський Національний Аграрний Університет
40021, вул. Герасима Кондратьєва, 160, м. Суми, Україна
http://orcid.org/0000-0001-9610-3087

Еліна Анатоліївна Захарченко
Кандидат сільськогосподарських наук, доцент
Сумський Національний Аграрний Університет
40021, вул. Герасима Кондратьєва, 160, м. Суми, Україна
http://orcid.org/0000-0002-9291-3389

Владислав Миколайович Зубко
Доктор технічних наук, професор
Сумський Національний Аграрний Університет
40021, вул. Герасима Кондратьєва, 160, м. Суми, Україна
https://orcid.org/0000-0002-2426-2772

Анотація. Передпосівна інокуляція сільськогосподарських культур дозволяє підвищити параметри, що впливають на урожайність та якість врожаю, це було доведено багатьма українськими та закордонними дослідниками. Метою роботи було встановити робочі параметри форсунок за різного тиску, що дало змогу розрахувати норму виливу робочого розчину під час сівби для створення системи припосівної інокуляції, що дозволить спростити процес обробки насіння та підвищити енергоефективність господарств. Для проведення експериментальних досліджень використовувалися методи системного та структурного аналізу, математичної статистики, абстрагування та математичного моделювання на основі рівняння Ейлера-Лагранжа, а також з використанням основ теоретичної механіки, фізики та теорії машин. Планування експерименту відповідало діючим стандартам, а для статистичної обробки даних використовувалися системи комп'ютерної графіки та програми Microsoft Excel. Завдяки проведеним дослідженням було встановлено кількість рідини, що може пропустити одна форсунка за 1 хв під тиском 300, 400 і 500 кПа. Було виявлено, що найменший результат показала форсунка діаметром 0,1 мм з тиском 300 кПа – 10,493 мл/хв, а найбільший – форсунка діаметром 0,8 мм і тиском 500 кПа – 146,379 мл/хв. Водночас, форсунки діаметром 0,4 – 0,6 мм використовують майже однакову кількість рідини під тиском 300 та 500 кПа. Було розраховано кількість рідини, що може бути вилито на 1 га за використання шестирядної просапної сівалки із шириною захвату 4,2 м на одну посівну одиницю кукурудзи. Отримані дані можуть бути використані при вдосконаленні будь-яких систем, де використовуються схожі форсунки, як то для розрахунку норми виливу сільськогосподарських оприскувачів чи систем, що дозволяють охолоджувати свинокомплекси під час літнього періоду

Ключові слова: експлуатація посівного комплексу; форсунка; урожайність; тиск; норма виливу; покриття насіння; біопрепарати; добрива; мікроорганізми; якість сівби

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 26(7), 149-159

UDC 633
DOI: 10.48077/scihor7.2023.149

Rice yield prediction using Bayesian analysis on rainfed lands in the Sumbing-Sindoro Toposequence, Indonesia

Abdul Aziz*
Post Graduate Student
Universitas Sebelas Maret
57126, 36 Ir. Sutami, Surakarta, Central Java, Indonesia
http://orcid.org/0000-0002-9688-3180
Komariah
Doctor of Applied Science, Soil Science, and Pydrometeorology
Universitas Sebelas Maret
57126, 36 Ir. Sutami, Surakarta, Central Java, Indonesia
https://orcid.org/0000-0001-7704-0754
Dwi Priyo Ariyanto
Doctor of Soil and Water Conservation
Universitas Sebelas Maret
57126, 36 Ir. Sutami, Surakarta, Central Java, Indonesia
https://orcid.org/0000-0001-6605-9599
Sumani
Doctor of Agroclimatology
Universitas Sebelas Maret
57126, 36 Ir. Sutami, Surakarta, Central Java, Indonesia

Article's History:
Received: 23.04.2023
Revised: 26.06.2023
Accepted: 13.07.2023

Abstract. Since rainfed rice fields typically lack nutrients, frequently experience drought, and require more fund to support farming operations, the production results become erratic and unpredictable. This research aims to construct location-specific rice yield predictions in the rainfed rice fields among the Sumbing-Sindoro Toposequence, Central Java, using a Bayesian method. This study is a survey with an exploratory descriptive methodology based on data from both field and laboratory research. Prediction model analysis using the Bayesian Neural Network (BNN) method on 12 geographical units, sampling spots were selected with intention. The following variables were measured: soil (pH level, Organic-C, Total-N, Available-P, Available-K, soil types, elevation, slope) and climate (rainfall, evapotranspiration). According to the statistical analysis used, the BNN model's performance has the highest accuracy, with an RMSE value of 0.448 t/ha, which compares to the MLR and SR models, indicating the lowest error deviation. To obtain the ideal parameter sampling design, parameter distribution is directly and simultaneously optimised using an optimisation technique based on Pareto optimality.

Suggested Citation:
Aziz, A., Komariah, Ariyanto, D.W., & Sumani. (2023). Rice yield prediction using Bayesian analysis on rainfed lands in the Sumbing-Sindoro Toposequence, Indonesia. *Scientific Horizons*, 26(7), 149-159. doi: 10.48077/scihor7.2023.149.

*Corresponding author

The top 7 data sets (slope, available-P, evapotranspiration, soil type, rainfall, organic-C, and pH) yielded the highest accuracy based on the test results for the three-parameter groups. The coefficient of determination has the highest value, 0.855, while the RMSE test for the model using the top 7 data set has the lowest error value at 0.354 t/ha and 18.71%, respectively. By developing location-specific rice yield predictions using a Bayesian method, farmers and agricultural practitioners can benefit from more accurate and reliable estimates of crop productivity

Keywords: Agricultural sustainability; Bayesian Neural Network (BNN); food security; rainfed rice field; yield prediction

INTRODUCTION

While just 26.91 million tonnes of rice were produced nationally in Indonesia in 2020, the country's overall rice consumption topped 30 million tonnes (Lotulung, 2020; Ministry of Agriculture, 2020). In order to meet the country's food needs, rainfed lowland areas are anticipated to provide for Indonesians who eat rice as their primary source of nutrition (Wihardjaka *et al.,* 2020). In Central Java, there are 77,532 hectares of rainfed paddy fields, and 342,777 tonnes of Milled Dry Grain (MDG) are produced annually, according to BPS Central Java Province, (2018). As a result, following irrigated lowland rice, rice produced from rainfed lowland rice now contributes the most to national rice production. The Indonesian government is still working on expanding the nation's rice production in several ways, one of which is by growing rice on drylands, such as rainfed lowland rice.

Difficulties in increasing rice yield in Indonesia include using inefficient farming techniques and parts of its rainfed rice fields, which are highly vulnerable to climate change (Ruminta *et al*., 2017). According to Rahayu (2014) the productivity of irrigated lowland rice fields is more significant due to more frequent planting than rainfed rice fields, which can only yield 1-2 times a year. In order to boost rice output, rainfed rice fields can be a valuable resource that needs to be adequately managed (Sinaga *et al.*, 2014).

As rainfed rice fields are typically nutrient deficient, often suffer from drought, and require more financing to sustain farming activities, production outcomes are unstable and unpredictable (Novia & Satriani, 2020). As noted by Murniati *et al.* (2017), in order to grow rainfed rice, farmers must be able to adapt to the environment and available resources. To maximise the yield of rainfed rice fields, farmers need to be aware of climate change, crop types, cropping patterns, irrigation management, and the right sowing period. Therefore, a yield prediction model is needed as a guide for adaptation during cultivation to facilitate effective management of rainfed rice fields.

Estiningtyas & Syakir (2018) argue that in crop production, the level of production is determined by three main factors: climate, soil, and plants. These three factors need to interact together with proper management to produce optimal yields. The lack of any one factor will affect production results. Site-specific cropping practices are a way of adapting cultivation to the local agro-ecosystem. According to Anupama & Lakshmi (2021), farmers need advice on the right planting time and cultivation methods with the best yield prediction model that is expected to yield the highest profit with little investment.

One of the most complex issues in precision agriculture is yield prediction. Since crop yields rely on various factors, including climate, soil, fertiliser use, and seed variety, yield prediction requires numerous data sets (Van Klompenburg *et al.,* 2020). The machine learning model is a methodology that can forecast yields since it can ascertain how plants react to elements that have an impact on crop output, such as the soil, the environment, cultivation methods, and seed kinds used (Pant *et al.,* 2021). Machine learning algorithms attempt to forecast crop yields based on empirical correlations between yield-driving elements and historical yield records rather than modelling biophysical processes in crop agriculture (Wang *et al.,* 2020). The Bayesian model is the machine learning model used in this research. According to *Drury et al.* (2017), Bayesian is appropriate for agriculture because it can represent interdependent causal elements or factors, give a general overview of partial or uncertain information, combine new information, and draw new conclusions using new information. Liu *et al.* (2017) pointed out that machine learning algorithms play a role in data-driven models to improve forecasting accuracy.

This research was conducted to identify yields in rainfed rice fields with a harvest prediction model based on specific soil and climate characteristics to provide recommendations regarding cultivation management efforts and planting time to reduce the risk of crop failure, especially in the Sumbing-Sindoro toposequences. Soil and climate characteristics variables were used in this study as a prediction basis for estimating crop yields. This prediction model is expected to help farmers determine the inputs and adaptations to obtain optimal results.

MATERIALS AND METHODS

Study area. The research was carried out on two mountain toposequences in Central Java, Indonesia, specifically on the southern slopes of Mount Sumbing and the southwest of Mount Sindoro (Fig. 1). To assess the nutrient level, soil samples were collected for the survey.

The study site's rainfed rice crops produced an average of 1.87 t/ha in harvest. This research used 21 site locations as research samples. These location points were made up of elevation, which were created at specific research locations based on the variety of environmental variables present there.

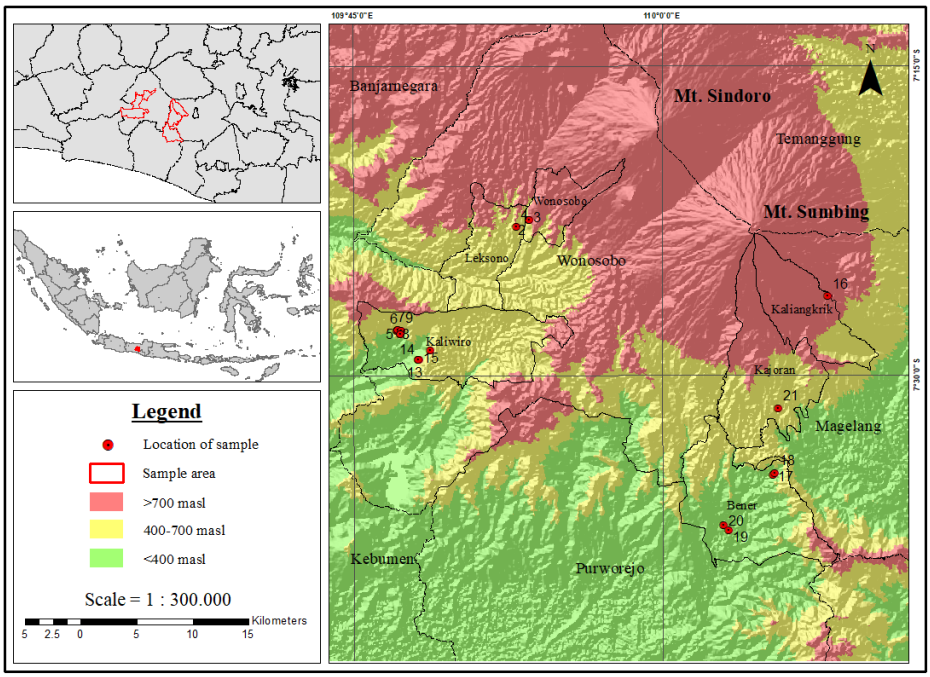

Figure 1. *Location of research toposequence (the southern slopes of Mount Sumbing and the southwest of Mount Sindoro)*

Research parameter. Characteristics of the soil and plant yield data recap. According on field observations and the outcomes of laboratory analyses of soil properties, this study employed data on soil characteristics in the field.

Table 1. *Research parameter about soil characteristics and yield on location-specific toposequence*

Soil and plant characteristics (unit)	Toposequences	
	Mount Sumbing	Mount Sindoro
Soil Characteristics		
pH	6	5-6
Organic-C (%)	1.45-5.27	1.18-5.98
Total-N (%)	0.54-1.40	0.64-1.01
Available-P (ppm)	2.39-9.55	0.29-7.65
Available-K (me/100g)	0.33-0.55	0.29-0.47
Type of soil	Inceptisols and Alfisols	Entisols, Inceptisols and Ultisols
Slope (%)	0-25	0-25
Plant yield data recap		
Yield (t/ha)	1.24-3.72	0.62-3.87

Note: *Analysis of soil characteristics based on Indonesian Soil Research Institute procedures (2009) and data on plant yield recap based on social survey carried out by researchers immediately at the research site*
Source: *compiled by the authors*

Characteristics of the climate. Climate is used in the model to assume the amount of water available and usable by plants. In the yield prediction model, climate factors affect crop productivity, and rainfall and air temperature are the main factors determining crop yields (M & B, 2021)which is a difficult task because of the climatic factors, soil fertility, nutrients and so on. Precise crop forecast requires fundamental

understanding of the functional association between crop and input parameters and to predict the crop yield in advance we developed an Adaptive Lemuria algorithm. Our proposed model comprises of Deep Belief Network for feature learning and pre-training, Decision tree & K-Means clustering (HDTKM. Two factors are used in this prediction model: rainfall and evapotranspiration. This analysis used rainfall and air temperature data as a database. The data were taken from climatology stations at the research site (2012-2021). The evapotranspiration calculation process uses the Thornthwaite method.

Table 2. *Research parameter about climate characteristics on location-specific toposequence*

Climate (unit)	Toposequences	
	Mount Sumbing	Mount Sindoro
Rainfall (mm/year)	3.954-4.874	3.024-3.445
Evapotranspiration (mm/day)	1.47-2.93	5.27-5.81

Note: *Analysis of climate characteristics based on climatology stations at the research site (2012-2021)*
Source: *compiled by the authors*

Particularly in rainfed rice fields, which require almost no input and rely on rainwater for irrigation, the specifics of a location's soil and climate significantly impact agricultural production. Soil and climate characteristics are used in this study as the primary predictor parameters in the model. Using the information on the physical properties of the land and the actual climate in the field, it will be conceivable to describe the land's potential for crop production (Abdalla *et al.*, 2019).

Bayesian Neural Network (BNN). The Bayes' theorem was developed into the BNN method, which utilises the posterior probability value of the input data to offer information through particular parameters. Machine learning research yields BNN, a tool for examining decision-making under ambivalent circumstances. Using probabilities that define the relationship between variables, Bayes' theorem can be used to reflect the impact on existing data in practice (Batta, 2020). The Bayes' theorem can be expressed as:

$$P(Y) = \frac{P(X)P(X)}{P(Y)} \quad (1)$$

In this study, the BNN method was used because, precisely, BNN can estimate the distribution of predictions through the interpretation of the uncertainty of the input parameters. The BNN analysis results used 21 data samples, with 10 input parameters consisting of 2 indicators: soil and climate. The data is running and tested using different numbers of neurons to get the most effective results and close to the actual results. A trial and error method is used to get the optimal number of neurons in a prediction model (Liu *et al.,* 2001). The framework of the analysis carried out in this study is shown in Figure 2.

This research uses BNN to produce accurate yield predictions through various input parameters. The concept is expected to explain the relationship between variables and produce a predicted crop yield that is close to the actual crop yield. The prediction model for rainfed rice yields was developed using regional and field data to obtain an accurate model through 2 mountain toposequences. In particular, the model developed based on the input parameters can be seen in Figure 2. By incorporating factors of land characteristics in the form of climate and actual soil characteristics in the field as supporting parameters to increase the accuracy of the prediction model, this research was conducted to obtain: machine learning model prediction of rainfed rice fields with actual and location-specific parameters.

Figure 2. *Framework of prediction yield using BNN*

Model accuracy analysis. The predictive model's capacity and reliability are evaluated using accuracy analysis, which is also used to rate the model. The coefficient of determination (R^2), root mean square error (RMSE), and mean absolute percent error were all calculated during the analysis (MAPE). The following equation is used:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(y_i - y)^2}{n}} \quad (2)$$

$$MAPE = \sum_{i=1}^{n}\left|\frac{y_i - y}{y_i}\right| \times 100\% \quad (3)$$

Note: *yi = prediction result; y = average actual yield; n = amount of data sample*

The research's reliance on the RMSE accuracy model aims to standardise the measurement of a model's inaccuracy in forecasting quantitative data, demonstrating how dispersed the data are around the most appropriate line (Ali *et al.,* 2023). The RMSE is calculated by dividing the error (yi-y) by the number of data points (n). Unlike the MAPE accuracy model, which is used to estimate a model's relative error magnitude, the MAPE approach is helpful when determining the forecast's accuracy depending on the size or magnitude of the forecast variable; in other words, MAPE tells how significant the prediction mistake is (Son *et al.,* 2022).

RESULTS AND DISCUSSION

Examining BNN neurons. Using the BNN methods, predictions of the rice crop in rice fields that receive rainwater were analysed. To find a model with the highest coefficient of determination (R^2) and the lowest RMSE value, prediction analysis using BNN starts by trial and error testing the data and the number of neurons.

Table 3. *Comparison of model accuracy and the number of neurons employed*

Model accuracy	Number of neurons employed									
	1	2	3	4	5	6	7	8	9	10
R^2	0.793*	0.741	0.716	0.695	0.683	0.677	0.669	0.694	0.655	0.656
RMSE (t/ha)	0.448*	0.505	0.530	0.549	0.560	0.564	0.572	0.550	0.583	0.582

Note: *R^2 = higher is better; RMSE = lower is better; * = better*
Source: *compiled by the authors*

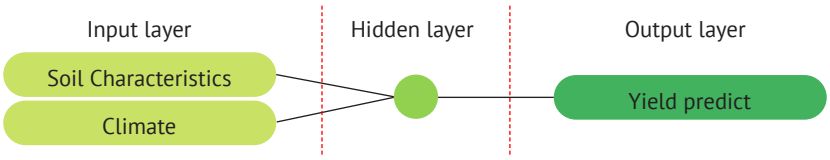

Figure 3. *Neuron of prediction yield using BNN*

The analysis was repeated ten times. Each checked the value of the neurons from 1 to 10, so that this analysis of BNN predictions was completed. According to the Table 3 above, neurons 1 through 10 have different R^2 and RMSE values. According to Table 3, the forecast of the rice harvest in fields that get rainwater is most suited for the criterion since it has an R^2 value of 0.793 and an RMSE of 0.448 t/ha. As the number of neurons used rises, performance in neuron testing declines.

BNN model performance. This research assessed the accuracy of two approaches for forecasting rainfed lowland rice yields. Stepwise Regression (SR) and Multiple Linear Regression (MLR) were the techniques utilised to compare the BNN model (SR). Multiple linear regressions, or MLR, is a statistical technique for predicting a value by integrating multiple parameters. While SR constructs the regression function based on the chosen parameters that have a strong relationship with the dependent variable, SR is a statistical development method from the regression method. Model evaluation criteria include RMSE, Pearson correlation, and R^2.

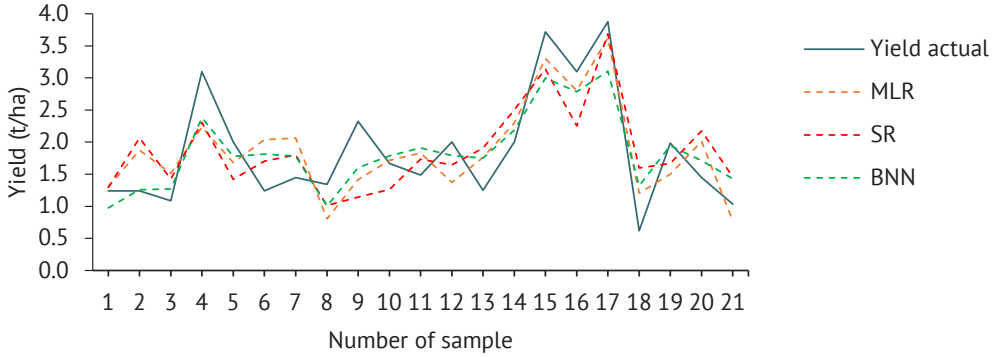

Figure 4. *BNN model performance compared to MLR and SR*

Figure 4 demonstrates that the results from the three prediction models are consistent with the actual yields. However, according to the statistical analysis used, the BNN model's performance has the highest accuracy, with an RMSE value of 0.448 t/ha, which compares to the MLR and SR models, indicating the lowest error deviation. These findings are further supported by the BNN model's Pearson correlation coefficient and coefficient of determination, which have the highest values at 0.890 for Pearson and 0.793 for R^2. The accuracy of the SR approach, on the other hand, is the lowest, with a Pearson value of 0.729 and an R^2 of 0.532. This demonstrates that the sensitivity of the BNN model outperforms that of the MLR and SR prediction techniques.

Table 4. *Comparison of an RMSE value to the MLR, SR, and BNN models*

Model accuracy	MLR	SR	BNN
R^2	0.643	0.532	0.793*
Pearson correlation	0.802	0.729	0.890*
RMSE (t/ha)	0.522	0.597	0.448*

Note: *R^2 = higher is better; RMSE = lower is better; * = better*
Source: *compiled by the authors*

According to (Abbaszadeh *et al.*, 2022), yield prediction is essential for agricultural planning and management and production and food security on a national and international level (Khaki & Wang, 2019) environment, and their interactions. Accurate yield prediction requires fundamental understanding of the functional relationship between yield and these interactive factors, and to reveal such relationship requires both comprehensive datasets and powerful algorithms. In the 2018 Syngenta Crop Challenge, Syngenta released several large datasets that recorded the genotype and yield performances of 2,267 maize hybrids planted in 2,247 locations between 2008 and 2016 and asked participants to predict the yield performance in 2017. As one of the winning teams, we designed a deep neural network (DNN. The Bayesian Neural Network is one of the models utilised in this study. Harvest prediction has now been widely established (BNN) (Semenova *et al.*, 2020). The two key input parameters for the model created in this study are soil and the actual field climate (Tables 1 and 2). Figure 3 findings demonstrate that when compared to the MLR and SR approaches, the prediction of rice harvest using BNN analysis yields results nearly identical to the actual and expected harvest values, with an R^2 coefficient of determination of 0.793. The research results of Singh Boori *et al.* (2022) showed that machine learning-based harvest prediction models produce higher sensitivity and accuracy with the regression method. Yield prediction using machine learning is a complex development influenced by soil parameters and environmental conditions (Velmurugan *et al.*, 2021).

Features importance analysis. The Pareto chart of standardised effects approach, which can display a parameter's impact on crop yields from largest to smallest, is then used in this research to examine the significance of parameters in the BNN model. To obtain the ideal parameter sampling design, parameter distribution is directly and simultaneously optimised using an optimisation technique based on Pareto optimality. A set of parameters with the maximum accuracy is produced using Pareto-measured importance features and the values of R^2, RMSE, and MAPE. The authors suggest the top 3, top 5, and top 7 parameters as three crucial ones. The effectiveness of these three parameter sets concerning the entire set of parameters is then evaluated.

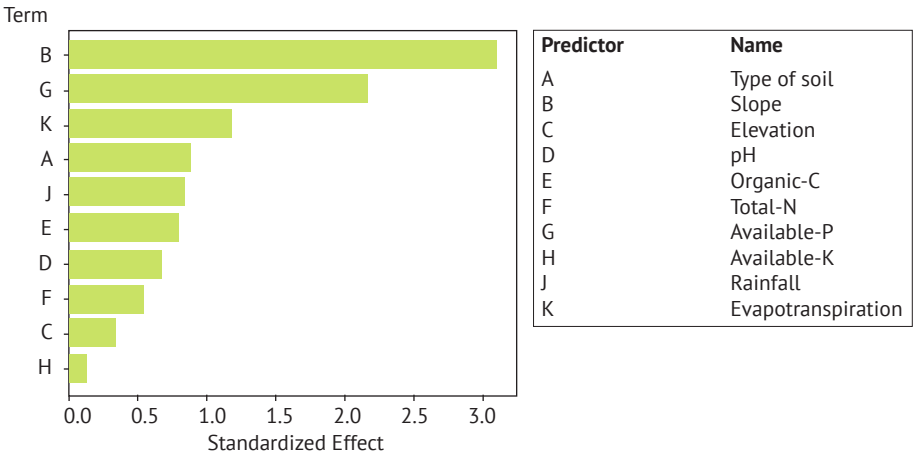

Figure 5. *Pareto chart of standardised effects*

The top 7 data sets yielded the highest accuracy based on the test results for the three-parameter groups (Fig. 6). According to parameter set testing, accuracy rises when more parameters are added but falls when the entire data set is used. The coefficient of determination has the highest value, 0.855, while the RMSE test for the model using the top 7 data set has the lowest error value at 0.354 t/ha and 18.71%, respectively. It is preferable to use the top 7 data sets, including slope, available-P, evapotranspiration, soil type, rainfall, organic-C, and pH.

Although irrigated rice fields are Indonesia's largest source of rice (Indonesia Ministry of Agriculture, 2020), rainfed rice fields still produce comparatively little rice compared to irrigated rice fields. Rainfall affects whether the rice harvest in fields nourished by the rain is successful or unsuccessful. According to Chakraborty & Newton (2011), irregular rainfall patterns and decreasing rainfall, which result in water stress throughout the plant growth stage, are to blame for the productivity of rainfed lowland rice fields.

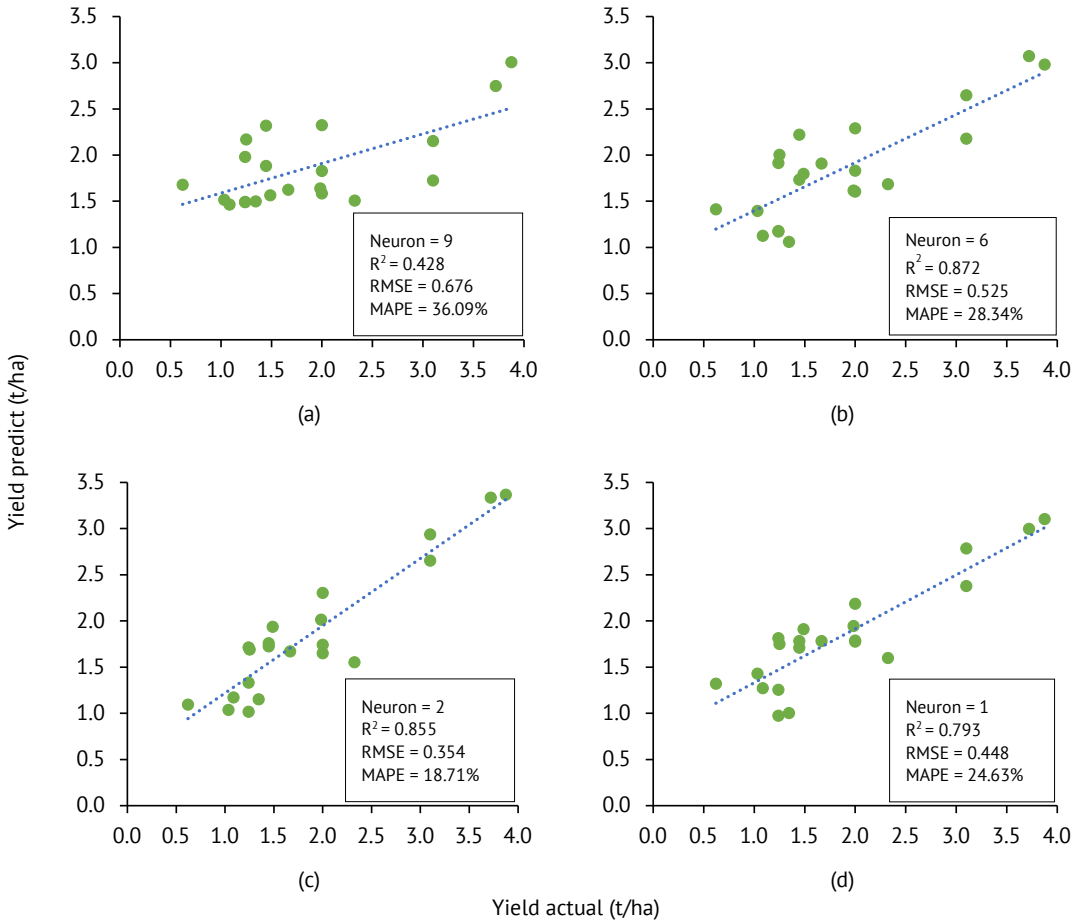

Figure 6. *BNN model by different feature sets; (a) top 3; (b) top 5; (c) top 7; (d) full set*

Using the Pareto approach, an experiment was conducted to improve performance and identify parameters that significantly impact yield prediction (Vojnov *et al.,* 2022) along with wheat, the most important staple crop in the Republic of Serbia, which is of great significance for ensuring national food security. With the increasing demand for food and forage, intensive agricultural practices have been adopted in the maize production systems. In this direction, considerable research efforts have been made to examine the effects of different types of cover crops as a green manure on maize productivity; however, no consistent conclusions have been reached so far. Therefore, the objective of the present study is to examine the possibility of predicting the effects of winter cover crops (CC. Following the tests, it was discovered that, as shown in Figure 6c, the model containing the top 7 data set parameters had the best accuracy. The accuracy of the yield from the prediction model and the actual outcomes are strongly correlated. An accuracy test can be used to verify this. The MAPE value obtained from this study is 18.71% and is within a reasonably practicable forecasting model capacity (0-20%), according to the BNN model accuracy test findings with the top 7 data sets (Maricar, 2019) a company can be running. The income in a company can be said is uncertain every few. So the required a calculation to predict the income of a company every few. In this case the applied calculation analyze methods of moving average with exponential smoothing with the value of the alpha 0.1, 0.5, 0.9, to calculate earnings forecasts

on the XYZ Company. Both methods compared to get a better method that have the highest accuracy value (the value of the smallest error. The results of the RMSE analysis, which measures the magnitude of the prediction results' error rate, likewise indicated good results with a value of 0.354 t/ha. The RMSE value measures a forecast's accuracy; the smaller (near 0) it is, the better. While Babaee *et al.* (2021) used input data on rainfall, permeability, soil texture, soil type, evapotranspiration, as well as inflow and outflow of water into paddy fields using the artificial neural networks (ANN) method, the study by Ma *et al.* (2021)the United States supplies more than 30% of the global corn production. Accurate and timely estimation of corn yield is therefore essential for commodity trading and global food security. Recently, several deep learning models have been explored for corn yield forecasting. Despite success, most existing models only provide yield estimations without quantifying the uncertainty associated with the predictions. Also, the traditional deep learning approaches typically require a large training set and are easily prone to overfitting when the number of samples in the training set is relatively small. To address these limitations, in this study, we developed a county-level corn yield prediction model based on Bayesian Neural Network (BNN regarding the prediction of corn harvest using satellite, climate, and soil data using the BNN method shows an RMSE value of 1.03 t/ha.

Smaller inputs will not reveal much about the algorithm's pattern throughout the BNN model's development, leading to a narrower stretch model (Baldos *et al.,* 2019). Typically, the input layer gathers various data from the outside world, and the neural network uses this data to process it for learning, recognition, or other purposes. Pareto analysis can improve the accuracy of the final prediction model and help with input efficiency in machine learning applications. In order to lower the danger of outliers when the BNN learns patterns from this algorithm, it is possible to delete factors from the Pareto process that are irrelevant to crop yields. By lowering the size of the stress-strain curve, Pareto makes the neural network less complex and increases the neural network's capacity for learning (He *et al.,* 2022).

Since BNN prediction analysis has been shown to have high accuracy and sensitivity, it has become a fascinating issue to explore in this era, particularly for diverse plant commodities (Hafezi *et al.,* 2021) a novel Learning Scenario Development Model (LSDM. The accuracy of the model with location and treatment-specific parameters has been demonstrated to enhance with the addition of more parameter components, particularly off-farm, in future research. Based on the results of this investigation, it was discovered that the BNN model predicts rainfed lowland rice yields with reasonable accuracy using input characteristics related to the soil and climate. The decrease of parameters while developing a model with superior performance proves that the outcomes of constructing the BNN model with Pareto are also satisfactory.

Crop yield predictions is crucially important in agricultural planning and management. It is also crucial to food production and security on a regional to global scale (Chhogyel *et al.,* 2020). Crop yield prediction that is reliable and timely allows for timely import and export decisions to promote and reinforce national food security (Basso & Liu, 2019). This is becoming increasingly essential as global warming and population growth continue. In agriculture, empirical connections have been routinely employed for crop production prediction. These approaches primarily rely on the assumption of linearity between crop output and other parameters such as canopy reflectance and meteorological data. The yield projections are particularly prone to overfitting due to severe non-linearity and a high degree of autocorrelation among these variables. To address this issue, many studies have effectively used Machine Learning (ML) models to estimate crop productivity.

CONCLUSIONS

By applying the Bayesian Neural Network (BNN) method to analyse prediction models across 12 geographical units, the study achieved the highest accuracy in yield predictions compared to the MLR and SR models. The BNN model demonstrated an RMSE value of 0.448 t/ha, indicating a low level of error deviation.

To optimise the parameter sampling design, an optimization technique based on Pareto optimality was employed, resulting in the selection of the top 7 variables (slope, available-P, evapotranspiration, soil type, rainfall, organic-C, and pH) that yielded the highest accuracy for the three-parameter groups. The coefficient of determination reached a value of 0.855, indicating a strong relationship between the variables. Additionally, the RMSE test for the model utilising the top 7 data set achieved the lowest error value at 0.354 t/ha and 18.71%, respectively.

The findings of this study contribute to the field of rainfed rice cultivation by providing location-specific predictions of rice yield, which can assist farmers and agricultural practitioners in making informed decisions and optimising resource allocation. By considering soil and climate variables, the developed model offers valuable insights into improving agricultural productivity and mitigating the risks associated with nutrient deficiency and drought in rainfed rice fields. Future research in the field of rainfed rice cultivation and yield prediction should focus on refining prediction models, expanding to other regions and crops, incorporating additional variables, conducting long-term monitoring and validation, integrating remote sensing and satellite data, and assessing the socio-economic implications for sustainable agricultural practices.

ACKNOWLEDGEMENTS

The authors thank to various parties who have adequately prepared this manuscript and Master Program

of Soil Science, Faculty of Agriculture Universitas Sebelas Maret Surakarta Indonesia.

CONFLICT OF INTEREST

None.

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Прогнозування врожайності рису з використанням байєсівського аналізу на богарних землях у топосекції Сумбінг-Сіндоро, Індонезія

Абдул Азіз
Аспірант
Університет Себелас Марет
57126, вул. Сутамі, 36, Суракарта, Центральна Ява, Індонезія
http://orcid.org/0000-0002-9688-3180

Комарія
Доктор прикладних наук, ґрунтознавства та гідрометеорології
Університет Себелас Марет
57126, вул. Сутамі, 36, Суракарта, Центральна Ява, Індонезія
https://orcid.org/0000-0001-7704-0754

Дві Прійо Аріянто
Доктор ґрунтознавства та охорони водних ресурсів
Університет Себелас Марет
57126, вул. Сутамі, 36, Суракарта, Центральна Ява, Індонезія
https://orcid.org/0000-0001-6605-9599

Сумані
Доктор агрокліматології
Університет Себелас Марет
57126, вул. Сутамі, 36, Суракарта, Центральна Ява, Індонезія

Анотація. Оскільки на богарних рисових полях зазвичай бракує поживних речовин, вони часто страждають від посухи і потребують більше коштів для підтримки сільськогосподарських операцій, результати виробництва стають нестабільними і непередбачуваними. Це дослідження має на меті побудувати прогнози врожайності рису на богарних рисових полях у топосистемі Сумбінґ-Сіндоро, Центральна Ява, з використанням байєсівського методу для конкретної місцевості. Це дослідження є опитуванням з дослідницькою описовою методологією, що ґрунтується на даних польових і лабораторних досліджень. Аналіз моделі прогнозування з використанням методу нейронних мереж Байєса (BNN) на 12 географічних одиницях, точки вибірки були обрані навмисно. Були виміряні наступні змінні: ґрунт (рівень pH, органічний вуглець, загальний азот, доступний фосфор, доступний калій, типи ґрунтів, висота, схил) та клімат (кількість опадів, випаровування). Відповідно до використаного статистичного аналізу, модель BNN має найвищу точність із середньоквадратичним відхиленням (RMSE) 0,448 т/га, що порівняно з моделями MLR та SR вказує на найнижче відхилення помилки. Для отримання ідеального дизайну вибірки параметрів, розподіл параметрів було оптимізовано безпосередньо і одночасно за допомогою методу оптимізації, заснованого на оптимальності за Парето. За результатами тестування для груп з трьома параметрами найвищу точність показали 7 найкращих наборів даних (нахил, доступний P, випаровування, тип ґрунту, кількість опадів, органічний вуглець та pH). Коефіцієнт детермінації має найвище значення – 0,855, в той час як тест RMSE для моделі, що використовує 7 найкращих наборів даних, має найнижче значення похибки – 0,354 т/га та 18,71 % відповідно. Розробляючи прогнози врожайності рису для конкретної місцевості за допомогою байєсівського методу, фермери та аграрні практики можуть отримати вигоду від більш точних і надійних оцінок продуктивності культури

Ключові слова: сільськогосподарська стійкість; нейронна мережа Байєса (BNN); продовольча безпека; богарне рисове поле; прогнозування врожайності

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 26(7), 160-170

UDC 338:43
DOI: 10.48077/scihor7.2023.160

Satisfying the consumer demand for agricultural products: Possibilities and its prediction

Vahid Amrahov*
Head of Department, Associate Professor
Azerbaijan State Agricultural University
AZ2000, 450 Ataturk Ave., Ganja, Azerbaijan
https://orcid.org/0000-0002-6401-8467
Farrukh Rahimli
PhD Student, Assistant
Bandirma Onyedi Eylul University
10200, Central Campus, Bandirma University Onyedi Eylül, Bandirma, Turkey
Azerbaijan State Agricultural University
AZ2000, 450 Ataturk Ave., Ganja, Azerbaijan
https://orcid.org/0000-0003-3748-0266
Narmin Mirzazadeh
Assistant
Azerbaijan State Agricultural University
AZ2000, 450 Ataturk Ave., Ganja, Azerbaijan
https://orcid.org/0000-0001-5060-0125
Gunay Ibrahimova
PhD Student, Assistant
Azerbaijan State Agricultural University
AZ2000, 450 Ataturk Ave., Ganja, Azerbaijan
https://orcid.org/0009-0005-8922-2359
Hajar Valizadeh
PhD Student, Assistant
Azerbaijan State Agricultural University
AZ2000, 450 Ataturk Ave., Ganja, Azerbaijan
https://orcid.org/0000-0003-1301-4236

Article's History:
Received: 18.04.2023
Revised: 20.06.2023
Accepted: 11.07.2023

Abstract. In the modern world, consumer preferences and demand for agricultural products are constantly changing. Meeting these demands efficiently and effectively is crucial for the sustainability and profitability of the agricultural sector. That is why it remains important to study the demand for agricultural products and find methods to predict it. The research aims to investigate the main factors that influence the demand for agricultural products. The main methods used in this study were analysis,

Suggested Citation:
Amrahov, V., Rahimli, F., Mirzazadeh, N., Ibrahimova, G., & Valizadeh, H. (2023). Satisfying the consumer demand for agricultural products: Possibilities and its prediction. *Scientific Horizons*, 26(7), 160-170. doi: 10.48077/scihor7.2023.160.

*Corresponding author

abstraction, forecasting and modelling. The article examines the level of demand satisfaction, the current situation and opportunities depending on the scale of the market, the volume of goods and services, based on the fact that the satisfaction of consumer demand is one of the current problems in the world. The relationship between the development of agriculture and meeting the demand for food products and solving the problem of starvation was emphasized. Factors affecting consumer demand in agriculture – consumption costs, number of consumers, gross agricultural product, consumer price index, consumer incomes were analysed. On the basis of econometric analysis, the dependence between the optimization of consumer demand and the indicators related to it was determined. Using multi-factor linear correlation and multi-factor linear regression models, were described the level of actual and regression model consumption costs, as well as the forecast for the next years. The study contributes new knowledge to assess the level of demand for agricultural products

Keywords: modelling; forecasting; revenue; consumption expenditure; price index

INTRODUCTION

With the deepening of the globalization process and the increase in the world population, the role of consumer demand in the market of goods and services is changing significantly. As economies become more interconnected and borders fade away, understanding and analysing consumer demand is becoming a pressing issue for the global economy. Estimating the scale and structure of consumer demand, as well as forecasting future trends, has become important for economic planning and decision-making. From this point of view, the assessment of the scale and structure of consumer demand, the perspective of its change is considered one of the most urgent problems of the world economy. The learning of demand also makes it possible to predict the size and capacity of the market, expected changes in the geography of production and consumption of goods and services. Thus, the assessment and forecasting of the current state of consumer demand plays a fundamental role in better adapting economic subjects to the current market conditions. Consumer demand in terms of food supply is directly related to the development of agriculture, which is considered one of the most important spheres of the economy. Of course, if the demand for food products in the world continues, it is inevitable that the consumer demand for agricultural products will also increase (Yan *et al.,* 2020; Tapki *et al.*, 2021). At the same time, the deepening of the starvation problem in many countries highlights the problem of improving the level of satisfaction of consumer demand for agricultural products. As such, it should be acknowledged that the study of consumer demand for agricultural products and ensuring that it is met to the greatest possible extent is still relevant.

Currently, a significant number of scientists are studying the issues of consumer satisfaction. As such, X. Liu & Zh. Kao (2022) investigated the factors that influence customer satisfaction with certain types of agricultural products in e-commerce. Based on the empirical study, the authors provide a list of factors that would help businesses improve customer satisfaction in such companies. A similar study was conducted by Zh. Lei *et al.* (2022), although they concluded on another industry that is not related to agriculture. The peculiarities of consumer behaviour in the agricultural sector were studied by R. Sridevi (2021). The scientist described the role of this factor in the agricultural segment and provided some advice for employees of the sector's enterprises in terms of further work with clients. W. Chunshang (2020) also addressed this issue in his study, building a model for factor analysis of satisfaction in the agricultural supply chain using e-commerce technologies. The scientist shows that among the satisfaction factors, the price of products no longer plays a leading role, while the quality of service and the products themselves become more important.

Thus, the research aims to investigate consumer demand for agricultural products and identify the main factors influencing this component. This will allow to meet the needs of the population more effectively in terms of consumption of agricultural products both by the state and individual enterprises.

MATERIALS AND METHODS

As part of the study, a regression-correlation model was created to assess the level of consumer demand satisfaction based on some of its characteristics. The model was built in the following stages:

1. Selection of factors included in the model: identification of factors affecting the dependent variable; checking the collinearity between the factors and selecting the next factors based on comparative assessment; final selection of factors and evaluation of the importance of criteria.

2. Selection of factors affecting the result among the factors.

3. Evaluation of criteria.

4. General evaluation and analysis of the model.

5. Evaluation of the results obtained as a result of practical use of the model and forecasting.

In correlation-regression analysis, the regression function X_1, X_2, …, Xz is used to characterize the relationship between the result (Y) and the factors influencing the result (X). This, in turn, determines how the Y expression will change for specific indicators of X. If

there are many factors affecting the result, a multivariate regression model is used. In this case, the goal is to design a model with multiple factors and determine their effect on the result (1):

$$y = f(x_1, x_{2,\dots,} x_m) + \varepsilon, \quad (1)$$

where: ε – random model error rate for different factors; x_n – characterising factors of independent variables; y – dependent variable. In this situation, x_1, x_2, …, x_m must meet the following requirements: they must be expressed with quantitative indicators; must be closely related to the outcome factor; factors should not be dependent of each other. In practice, depending on the forms of dependence, are used linear and non-linear models of the multifactor regression model. So, according to the linear regression model, the coefficients aj, j=1, 2, …, m characterizes the average change of the result with the change of the xj factor, in case other factors remain unchanged and expressed in the following form (2):

$$Y = a_0 + a_1x_1 + a_2x_2 + \dots + a_mx_m + \varepsilon, \quad (2)$$

where: a_j (j=0, 1, 2 … m) – coefficients that characterise the average change in the output variable. It should be noted that within this study the y – is consumer costs, x_1 – consumer demand; x_2 – total agricultural output; x_3 – consumer income; x_4 – consumer product price index.

Thus, many different scientific methods were used in the research. One of them was analysis, which allowed to draw conclusions based on the selected qualitative and quantitative data and use them in further work. Modelling was used to build a correlation and regression model and assess the impact of selected factors on consumer demand for agricultural products. Abstraction allowed to avoid assessing the impact of individual minor factors. Forecasting allowed to conclude in terms of the future volume of consumer demand for agricultural products.

RESULTS

Consumer demand is formed under the influence of many factors. From this point of view, in the research on the level of satisfaction of consumer demand, statistical data covering the last 15 years on important indicators such as consumer expenses, number of consumers, consumer price index, gross agricultural product, and consumer incomes. Considering the multitude of factors affecting the level of satisfaction of consumer demand, it is necessary to include various independent variables in the modelling of consumer demand. However, a significant increase in the number of factors in a dynamic model requires an increase in primary data. This increases the importance of the consumer demand model. Considering the mentioned, comparative analysis, multivariate correlation-regression analysis and forecasting methods are used in the research based on the necessary statistical data on agriculture. The model provides a basis for predicting the future behaviour of each indicator on the change of any element by determining the characteristics of the factors affecting consumer demand. Thus, the model clearly shows all the relationships of the variables, is expressed in terms of quantity, and allows to prepare a more accurate and qualitative forecast.

Modelling consumer demand for agricultural products is important in determining the factors affecting the level and possibilities of demand satisfaction, as well as the volume of products that consumers will demand in the future. In fact, each factor affects the volume of demand to a different degree. In this regard, the modelling of the factors affecting consumer demand – consumption costs, number of consumers, consumer price index, gross agricultural product, consumer income – based on regression-correlation analysis is accompanied by high accuracy and stability. Regression and correlation analyses are carried out to determine the effect of various independent variables depending on the changes occurring in the studied object. In the optimization of consumer demand, the study of the dependence between the indicators related to necessity of great importance and makes the implementation of econometric analyses.

Looking at the level of satisfaction of consumer demand based on the annual consumption norms of the main types of agricultural products in the minimum consumption basket and the actual consumption per person, it becomes clear that in the years 2005-2021, in the analysis was carried out generally increasing dynamics is observed. Changes in other types of products, except for eggs, potatoes, vegetables and melon products, can be grouped into 3 periods: 2005-2010 – the period when the level of satisfaction of consumer demand was lower than the annual consumption norms (only in 2010 in milk and milk products result recorded as 101.1%); 2011-2016 – the period when growth fluctuated between 3-6% and 2017-2021 – the period when growth rose to 30%. In 2005-2014, the demand for egg products was not met, in other years there was an increase in the indicator, while in potato, vegetable and melon products, of the analysis the level of satisfaction of consumer demand exceeded the annual consumption norms (Tables 1-3).

Table 1. *Annual consumption norms of the main types of agricultural products for the minimum consumption basket, kg*

Products	Consumption norms
Meat and meat products	31.5
Milk and milk products (by turning into milk)	232.3

Table 1, Continued

Products	Consumption norms
Eggs, pcs	153
Potato	50.6
Vegetables and melon products	96.9

Source: *Annual consumption norms of the main types of food products for the minimum consumption basket (2022)*

Table 2. *Actual consumption per person, kg*

Years	Meat and meat products (by turning into meat)	Milk and milk products (by turning into milk)	Eggs, pcs	Potato	Vegetables and melon products
2005	29	170	98	91	175
2006	28	173	86	96	181
2007	30	174	106	88	175
2008	30	176	118	81	163
2009	31	221	127	81	157
2010	31	235	125	73	160
2011	32	246	131	72	166
2012	32	241	127	73	157
2013	33	243	138	74	152
2014	33	247	152	73	148
2015	33	246	154	72	154
2016	35	236	156	75	146
2017	37	238	158	75	143
2018	40	240	153	73	148
2019	41	246	165	82	166
2020	41	258	175	83	172
2021	41	253	170	84	176

Source: *Per capita consumption of food products (2022)*

Table 3. *Level of satisfaction of consumer demand, %*

Years	Products				
	Meat and meat products (by turning into meat)	Milk and milk products (by turning into milk)	Eggs, pcs	Potato	Vegetables and melon products
2005	92	73.1	64	179.8	180.5
2006	88.8	74.4	56.2	189.7	186.7
2007	95.2	74.9	69.2	173.9	180.5
2008	95.2	75.7	77.1	160	168.2
2009	98.4	95.1	83	160	162
2010	98.4	101.1	81.6	144.2	165.1
2011	101.5	105.8	85.6	142.2	171.3
2012	101.5	103.7	83	144.2	162
2013	104.7	104.6	90.1	146.2	156.8
2014	104.7	106.3	99.3	144.2	152.7
2015	104.7	105.8	100.6	142.2	158.9
2016	111.1	101.5	101.9	148.2	150.6
2017	117.4	102.4	103.2	148.2	147.5
2018	126.9	103.3	100	144.2	152.7

Table 3, Continued

Years	Products				
	Meat and meat products (by turning into meat)	Milk and milk products (by turning into milk)	Eggs, pcs	Potato	Vegetables and melon products
2019	130.1	105.8	107.8	162	171.3
2020	130.1	111	114.3	164	177.5
2021	130.1	108.9	111.1	166	181.6

Source: *compiled by the authors*

As it can be seen, the analysis of the level of satisfaction of consumer demand in the natural expression does not allow to determine the factors affecting it. As mentioned above, the level of satisfaction of consumer demand is formed by the influence of various indicators. In this regard, it is important to consider that consumer spending means the amount, directed to the satisfaction of consumer demand. That is, the need to determine the effect of those indicators on individual product types not in natural terms, but in terms of value, requires the investigation of the factors that shape consumption costs. This situation gives a reason to take consumer expenses as the dependent variable in consumer demand modelling and regression-correlation analysis, and the number of consumers, the consumer price index, the total agricultural product, investments in the agricultural sector, and consumer income as the independent variables. In general, correlation-regression analysis, which is considered one of the main methods of econometrics, expresses the relationship between economic variables with quantitative indicators.

For the research, a regression-correlation model was constructed, some of the characteristics and features of which are described in Materials and Methods. Based on the above, using statistical data, the relationship between consumer spending (Y), which forms the level of consumer demand, and the number of consumers (X1), total agricultural output (X2), consumer incomes (X3), consumer price index (X4) can be determined (Table 4).

Table 4. *Consumer spending and the dynamics of main indicators affecting it*

Years	Consumption expenses, million manats (Y)	Number of consumers, thousand people (X1)	Common agricultural product, at actual prices, million manats (X2)	Consumer incomes, million manats (X3)	Consumers price index, % (X4)
2005	5532.6	8553.1	1844.8	8063.6	110.9
2006	6873.1	8666.1	2115.5	10198.5	111.9
2007	9374.6	8779.9	2918.6	14558.2	116.2
2008	13286.2	8922.5	3505.9	20735.4	128.6
2009	15048.9	8997.6	3805.5	22601.1	98.5
2010	16528.5	9111.1	3877.7	25607	107.2
2011	19216	9235.1	4525.2	30524.6	110.4
2012	21389.9	9356.5	4844.6	34769.5	100.2
2013	24150	9477.1	5244.6	37562	102.2
2014	26582.6	9593	5225.8	39472.2	101
2015	30595.3	9705.6	5635.3	41744.8	106.1
2016	35196.7	9810	5632.4	45395.1	114.7
2017	40210.2	9898.1	6580	49187.9	116.4
2018	43067.3	9981.5	7010	53103.7	101.7
2019	46797.8	10067.1	7836.7	56769	103.8
2020	43899.5	10119.1	8428.9	55754.1	105
2021	48378.2	10156.4	9163.4	57181.5	108.1

Source: *compiled by the authors*

First, let's build a multifactor linear regression model. With this probability, the double linear regression analysis shows that the influence of other factors on consumer spending is stronger, except for the consumer price index. Therefore, a regression analysis by removing the consumer price index from the model can be conducted (Tables 5-7).

Table 5. *Multifactor linear correlation model*

	Column 1	Column 2	Column 3	Column 4	Column 5
Consumer spending	1				
Number of consumers	0.986373329	1			
Common agricultural product	0.976433181	0.978809859	1		
Consumers' incomes	0.985859563	0.99709786	0.984041652	1	
Consumer price index	-0.264944043	-0.313870079	-0.302063766	-0.327146296	1

Source: *compiled by the authors*

Table 6. *Multifactor linear regression model*

Regression statistics					
Multifaceted R (multiple R)			0.9896874		
R^2 determination coefficient			0.9794811		
Normalized R			0.974746		
The standard error			2301.2225		
Observations			17		
Analysis of variance					
	DF	**SS**	**MS**	**F**	**F-importance**
Regression	4	3.29E+09	1.1E+09	206.8543	3.22E-11
Residue	13	68843124	5295625		
Total	16	3.36E+09			

Source: *compiled by the authors*

Table 7. *The result of a big number of regression model for the factors affecting consumption expenditure*

	Coefficient	Standard deviation	T-statistics	P-importance	Low 95%	Top 95%
Intersection	-163640.89	124426.7	-1.31516	0.211183	-432448	105166.7
X_1	19	15.00513	1.266395	0.227594	-13.4142	51.41903
X_2	2.1	1.209197	1.734086	0.106536	-0.51546	4.709163
X_3	-0.01	0.513562	-0.01763	0.986199	-1.11854	1.100428
X_4	-163640.89	124426.7	-1.31516	0.211183	-432448	105166.7

Source: *compiled by the authors*

Based on the linear regression model is obtained the formula (3):

$$Y = -163640.89 + 19x_1 + 2.1x_2 - 0.01x_3. \quad (3)$$

Using this formula, the level of consumer spending according to the regression model can be determined (Table 8, Fig. 1).

Table 8. *Actual and regression model level of consumption expenses, in million manats*

Years	Consumer spending	Consumer spending (based on model)
2005	5532.6	2661.4
2006	6873.1	5355.6
2007	9374.6	9160.7
2008	13286.2	13041.6
2009	15048.9	15079.1
2010	16528.5	173571.1
2011	19216	21023.7

Table 8, Continued

Years	Consumer spending	Consumer spending (based on model)
2012	21389.9	23958.6
2013	24150	27062.1
2014	26582.6	29205.6
2015	30595.3	32182.2
2016	35196.7	34123.2
2017	40210.2	37749.1
2018	43067.3	40197.6
2019	46797.8	43523.4
2020	43899.5	45765.2
2021	48378.2	48002.03

Source: *compiled by the authors*

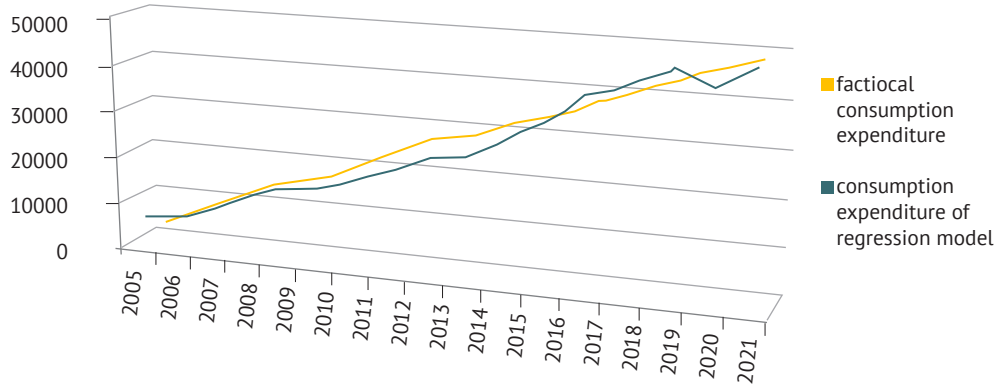

Figure 1. *Graphical representation of the actual and regression level of consumer spending*

As can be seen from the chart, the actual and regression model level of consumer spending changed in different directions over the years of the study. Thus, the actual consumption costs are ahead of the growth rate of consumption costs according to the regression model in 2005, 2006, 2015, 2016, 2017, 2018, 2019. The opposite situation, that is, according to the regression model, the increase of consumption expenses compared to actual consumption expenses coincides with the years 2007-2014, 2019-2021. One of the main goals of the research is the forecasting of consumption costs according to the regression model. The corresponding calculations for the period up to 2030 show that the dynamic increase of consumption costs according to the regression model (in the range of 51830.92-78633.2 million manats) is expected due to the influence of the factors included in the model. At the same time, one of the points that is important to pay special attention to is the consideration of the purchasing power of all age groups of the population along with the average indicators in the regularity between consumption costs and consumption demand (Fig. 2).

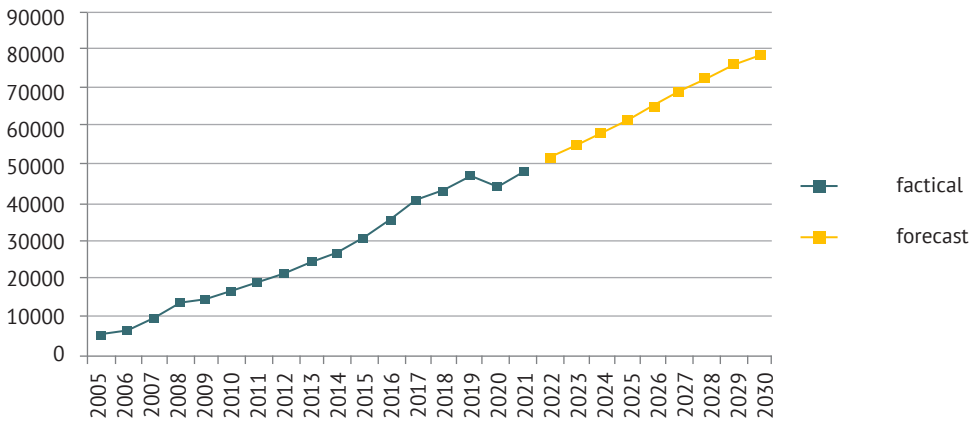

Figure 2. *Graphical representation of the forecast of consumption expenditure according to the regression model*

Such an approach can make it possible to determine the possibilities of meeting the consumer demand for all categories of the population and eliminate the problems that may arise in time.

DISCUSSION

According to the neo-classical theory of demand, the main decision-maker regarding the realization of products is the consumer. Consumer demand is formed not only based on need, but also on the basis of consumers entering the market as buyers. Cang & Wang (2021) one of the famous economists of the 19th century, argued that the growth rate of the world's population would be higher than the rate of food production with his population theory. Accordingly, greater problems are predicted to emerge in the future if the balance is not tipped in favour of food production. Based on the theory put forward by the German economist Jaeger *et al.* (2023) as the income of individuals increases, the share allocated to food products from this income increases in absolute value, and the share allocated to better goods and services rises proportionally. Guo *et al.* (2022) also gave special importance to the importance of agricultural products, which have an important place in human nutrition. Liu *et al.* (2023) extensively researched consumer demand for agricultural products in terms of purchasing power and identified factors affecting consumer behaviour. Based on research, it can be noted that consumer behaviour is formed by the influence of product, market, and environmental factors. Consumer behaviour affects the change in the level of social productivity and the standard of living of consumers (Lopez-Bonilla *et al.*, 2021).

Liu & Zhang (2023), Nie *et al.* (2021), and Sun *et al.* (2023) have also conducted extensive research and put forward various opinions on the formation, forecasting and modelling of consumer demand. As the main common feature of the studies conducted based on generalizations, it can be shown that consumer demand has subjective characteristics, acceptance, and defence of the idea that consumer demand is formed depending on the current economic and social situation. Although the need for food products has universal characteristics, consumer demand manifests itself in the presence of differences between countries, even between individual regions of the same country. This requires a complex approach to the problem not only in terms of general aspects, but also in terms of determining and predicting the impact of quantitative indicators.

The role of customer satisfaction is described by Xie *et al.* (2022) and Tang *et al.* (2023). The authors note that consumers are more attracted to the products/services of organisations that most closely meet their specific needs in any market segment. In other words, private sector representatives should pay more attention to the needs of their target audience and try to meet them. This will not only increase their profits but will also improve the efficiency of the economy and the overall welfare of the country. The factors that influence user satisfaction in agricultural e-commerce applications were studied by A.N. Nusifera *et al.* (2020). Their study found that most agricultural e-commerce users were women in their 20s and 30s, often married and well-educated. They worked as private employees or civil servants. In assessing user behaviour, the researchers concluded that variables such as price and customer service did not have a significant impact on satisfaction, while others had a more significant impact. Therefore, the researchers conclude that to maintain satisfaction and loyalty, suppliers should simplify the delivery process and provide good information about it both on specialised platforms and in offline meetings. The researchers also note that the data collection was conducted before the COVID-19 pandemic, and therefore the actual data may vary slightly. Overall, this study provides insights into how to ensure a higher level of satisfaction with the consumption of agricultural products at the enterprise level, while the research above analyses the situation at a more global level.

The possibilities of meeting the needs of consumers of agricultural products were also considered by S. Yekimov *et al.* (2021). The researchers emphasise the increasing role of the quality of products on the structure of demand for them. They note that in a highly competitive market, the focus of production on high-quality products is the basis for the successful functioning of an enterprise, and the usefulness of a product or service for its consumer is not limited to its material characteristics but is also inextricably linked to the purchase of this product or service. Thus, scientists also highlight the role of non-price factors and the importance of taking them into account by enterprises when creating their policies in the context of doing business in the agricultural sector. More globally, G. Guan *et al.* (2022). Their study shows that COVID-19 has a significant impact on logistics, products, and platform factors. It was found that logistics factors, i.e., the ability to deliver products efficiently and easily, as well as product (quality) and platform (through which the product was sold) factors had the greatest impact on customer satisfaction. Given that among the three selected factors, the COVID-19 crisis had the greatest impact on the logistics component, it can be understood that this significantly reduced the ability to meet the demand for agricultural products. Unfortunately, the authors pay little attention to the price factor. A detailed study of the demand for agricultural products was conducted by T. Tempesta *et al.* (2019). They focused on social farms, i.e., those where production is conducted in compliance with all ethical standards. Their study showed that consumers are willing to pay extra to be able to consume products grown on such farms. This again underlines the changes taking place in terms of demand for agricultural products, which are aimed at moving away from traditional price values in shaping demand towards new ones.

Thus, the satisfaction of consumer demand shows an upward trend over the years, with fluctuations observed in different periods. The regression analysis showed that there are a significant number of factors influencing the consumption of agricultural products other than the consumer price index; moreover, its removal from the model made the model more accurate. All of this makes it somewhat difficult to make forecasts for future consumption of agricultural products, but it still allows to make some estimates, as demonstrated in the paper above. The finding that consumer demand is significantly influenced by factors other than the price suggests that changes in policy in this area are needed among government officials. In addition, the private sector should also change some of its behavioural patterns in the market to optimise external demand.

CONCLUSIONS

Based on the research, authors can note that the study of the level of satisfaction of consumer demand for agricultural products is important, first, in terms of determining the possibilities of meeting the needs of the population more fully. Agriculture can develop continuously if the demand for the products of this field increases. This is possible provided that the consumer demand for the products is determined and its economic justification is provided.

The research of consumer demand is aimed at determining the trends of its formation, determining the factors affecting the change in demand. When studying the demand, it is necessary to differentiate between realized, unsatisfied and expected demand. Realized demand determines the actual satisfaction of consumers' demand for individual products. Unsatisfied demand reflects unsatisfied demand due to unavailability of needed products or low purchasing power of consumers. The purpose of studying expected demand is to consider changes that may occur due to the introduction of new products to the market or the expansion of demand. The research of consumer demand is used to determine the range and quality of manufactured products, as well as existing and expected demands, based on the analysis of the data obtained in this process. In this regard, the study of the factors affecting consumer demand allows to draw a number of generalized conclusions in this field: the correlation model requires to make reasonable assessments by determining the level of influence of the number of consumers, the volume of the total product, the income of consumers and the consumer price index on the consumption costs that determine its level; on the basis of the regression model, it was possible to determine the change trends of consumption expenses under the influence of the mentioned factors; correlation-regression models make it possible to predict the changes that may occur for the next years by calculating the individual and complex effects of factors.

Thus, based on what has been mentioned, it can be said that the econometric models built for the purpose of determining and forecasting consumer demand for food products are fundamental factors in determining the measures to increase the volume of production, deliver the manufactured products to consumers, improving the quality of products, increasing the purchasing power of the population, and regulate the price level.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Задоволення споживчого попиту на сільськогосподарську продукцію: можливості та прогноз

Вахід Тофік Амрахов
Доцент
Азербайджанський державний аграрний університет
AZ2000, просп. Ататюрка, 450, м. Гянджа, Азербайджан
https://orcid.org/0000-0002-6401-8467

Фаррух Мухамад Рахімлі
Аспірант, асистент
Університет Бандирма Оньєді Ейлюль
10200, Центральний кампус Університету Бандирма Онєді Ейлюль, Бандирма, Турція
Азербайджанський державний аграрний університет
AZ2000, просп. Ататюрка, 450, м. Гянджа, Азербайджан
https://orcid.org/0000-0003-3748-0266

Нармін Габіль Мірзазаде
Асистент
Азербайджанський державний аграрний університет
AZ2000, просп. Ататюрка, 450, м. Гянджа, Азербайджан
https://orcid.org/0000-0001-5060-0125

Гюнай Арзу Ібрагімова
Асистент
Азербайджанський державний аграрний університет
AZ2000, просп. Ататюрка, 450, м. Гянджа, Азербайджан
https://orcid.org/0009-0005-8922-2359

Хаджар Шохрадін Валізаде
Асистент
Азербайджанський державний аграрний університет
AZ2000, просп. Ататюрка, 450, м. Гянджа, Азербайджан
https://orcid.org/0000-0003-1301-4236

Анотація. У сучасному світі споживчі переваги та попит на сільськогосподарську продукцію постійно змінюються. Ефективне та результативне задоволення цих вимог має вирішальне значення для стійкості та прибутковості сільськогосподарського сектора. Тому актуальним залишається вивчення попиту на сільськогосподарську продукцію та пошук методів його прогнозування. Метою дослідження є вивчення основних факторів, що впливають на попит на сільськогосподарську продукцію. Основними методами, використаними в цьому дослідженні, є аналіз, абстракція, прогнозування та моделювання. У статті досліджено рівень задоволення попиту, поточну ситуацію та можливості в залежності від масштабу ринку, обсягу товарів і послуг, виходячи з того, що задоволення споживчого попиту є однією з актуальних проблем у світі. Наголошено на взаємозв'язку розвитку сільського господарства із задоволенням попиту на продукти харчування та вирішенням проблеми голоду. Проаналізовано фактори, що впливають на споживчий попит у сільському господарстві – витрати на споживання, кількість споживачів, валовий сільськогосподарський продукт, індекс споживчих цін, доходи споживачів. На основі економетричного аналізу встановлено залежність між оптимізацією споживчого попиту та пов'язаними з нею показниками. Використовуючи багатофакторну лінійну кореляційну та багатофакторну лінійну регресійну моделі, описано рівень фактичних та регресійних моделей споживання, а також прогноз на наступні роки. Дослідження вносить нові знання для оцінки рівня попиту на сільськогосподарську продукцію

Ключові слова: моделювання; прогнозування; дохід; споживчі витрати; індекс цін

Журнал
«НАУКОВІ ГОРИЗОНТИ»

Том 26, № 7
2023

(Англійською мовою)

Редагування англомовних текстів:
С. Воровський

Відповідальний редактор:
Д. Кокра

Редагування бібліографічних списків:
Д. Кокра

Комп'ютерна верстка:
М. Кришталь

Підписано до друку з оригінал-макета хх.хх.2023
Ум. друк. арк. 20

Видавництво: Поліський національний університет
10008, б-р Старий, 7, м. Житомир, Україна
Тел. (0412) 22-04-17
E-mail: info@sciencehorizon.com.ua
www: https://sciencehorizon.com.ua

Journal
"SCIENTIFIC HORIZONS"

Volume 26, No. 7
2023

Editing English-Language Texts:
S. Vorovsky

Managing Editor:
D. Kokra

Editing Bibliographic Lists:
D. Kokra

Desktop Publishing:
M. Kryshtal

Signed to the print with the original layout xx/xx/2023
Conventional Printed Sheet 20

Publisher: Polissia National University
10008, 7 Staryi Bvld., Zhytomyr, Ukraine
Tel. (0412) 22-04-17;
E-mail: info@sciencehorizon.com.ua
www: https://sciencehorizon.com.ua/en