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CURRENT STATE OF SUNFLOWER BREEDING FOR RESISTANCE TO MAJOR DISEASES AND OPTIMIZATION OF THE CROP PROTECTION AGAINST PATHOGENS

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Sunflower, which can secure a profit of up to 80% or even more provided that its cultivation technology is adhered to, is one of the most profitable crops in Ukraine. This crop is the third biggest oil crop in the world in terms of production, with a total share of almost 10%. The global sunflower production in 2021/22 showed the record results for all the time: 57,200,000 tons. The sunflower production became an absolute record for Ukraine: 17,500,000 tons or 31% of the global volume. In 2021/22, the harvest area in the world amounted to 28,750,000 hectares, which is 7% more than in the previous season and the largest increase in the last 5 years. In Ukraine, the harvest area was 7,100,000 hectares or 25% of the global acreage. As to yield, our country is among the 10 TOP producers, with a yield of 2.46 t/ha, being only behind Hungary (2.81 t/ha) and France (2.76 t/ha). However, the high economic efficiency of the crop leads to the oversaturation of crop rotations with sunflowers and the evolvement of new virulent races of many pathogens of infectious diseases. As the phytosanitary condition of sunflower fields is worsened, new trends in breeding, which require comprehensive studies of the crop biology and its pathogens, are developed. Due to the climate instability, non-observance of at least the basic requirements for crop rotation and the crop cultivation technology, insufficient amount of sowing equipment, improper attitude to seed quality, neglect of hybrid selection, aand disease-inflicted damage of fields, the biological potential of sunflower in our country is only 50%. This indicates an insufficient knowledge of the peculiarities of sunflower cultivars' and hybrids' responses to stressful growing conditions as well as of prevalence and development of diseases and pests on the crop. Research into the prevalence, development, and harmfulness of major diseases of sunflower, determination of the species composition of pathogens, description of morpho-biological features of pathogens, and optimization of existing measures to protect the crop against diseases are prerequisites for the creation of highly productive hybrids. The world scientific practice shows that agricultural crop breeding for resistance to diseases and protective measures should be based on a deep knowledge of the pathogen nature and development, symptoms and harmfulness of the disease.

Key words: *sunflower, pathogen, symptoms, harmfulness, variety, hybrid, plasticity, resistance, tolerance, population, damage.*

Стороженко Д.С., Жукова Л.В., Станкевич С.В. Сучасний стан селекції соняшнику на стійкість до основних захворювань та оптимізація захисту посів від патогенів
Однією з найбільш рентабельних культур в Україні є соняшник, який за дотримання технологій його вирощування може забезпечити прибуток до 80 і більше відсотків [1]. Дана культура є третьою за величиною серед виробництва олійних культур у світі, із загальною часткою майже 10%. Результати світового виробництва соняшнику

у 2021/22 МР показали рекордні результати за весь час – 57,2 млн т. Виробництво соняшнику стало абсолютним рекордом для України – 17,5 млн т або 31% від світового об'єму. У 2021/22 МР у світі збиральна площа склала 28,75 млн га, що на 7% більше попереднього сезону і найбільший результат приросту за останні 5 років. В Україні збиральна площа склала 7,1 млн га або 25% від загальної кількості у світі. За врожайністю країна займає одну з провідних позицій з показником у 2,46 т/га, а у ТОП-10 виробників культури перше місце за Угорщиною – 2,81 т/га та друге за Францією – 2,76 т/га [2]. Але висока економічна ефективність культури призводить до перенасичення нею сівозмін, і як наслідок, формування нових вірулентних рас багатьох збудників інфекційних хвороб [3]. В результаті погіршення фітосанітарного стану посівів соняшнику з'являються напрями в селекції, які потребують всебічного вивчення біології культури та патогенів [4]. Через нестабільність кліматичних умов, недотримання хоча б основних вимог сівозмін та технології вирощування культури, недостатня кількість посівної техніки, неналежне ставлення до якості посівного матеріалу та підбору гібридів а також ураженість посівів хворобами біологічний потенціал соняшнику в нашій країні становить лише 50% [5]. Що свідчить про недостатній рівень вивченості особливостей реакції сортів та гібридів соняшнику на стресові умови вирощування, рівня поширеності й розвитку хвороб та шкідників на посівах культури [6]. Необхідною умовою для створення високопродуктивних гібридів є вивчення поширеності, розвитку, та шкідливості основних хвороб соняшнику, визначення видового складу патогенів, морфо-біологічних властивостей збудників та оптимізація існуючих заходів захисту культури від хвороб [7]. Світова наукова практика свідчить, що селекція сільськогосподарських культур на стійкість до хвороб та заходи захисту повинні базуватися на досконалому знанні природи патогена, його розвитку, симптоматики та шкодочинності хвороби [8].

Ключові слова: *соняшник, патоген, симтоматика, шкодочинність, сорт, гібрид, пластичність, стійкість, толерантність, популяція, ураженість.*

Statement of the problem. Sunflower, which can secure a profit of up to 80% or even more provided that its cultivation technology is adhered to, is one of the most profitable crops in Ukraine [1]. This crop is the third biggest oil crop in the world in terms of production, with a total share of almost 10%. The global sunflower production in 2021/22 showed the record results for all the time: 57,200,000 tons. The sunflower production became an absolute record for Ukraine: 17,500,000 tons or 31% of the global volume. In 2021/22, the harvest area in the world amounted to 28,750,000 hectares, which is 7% more than in the previous season and the largest increase in the last 5 years. In Ukraine, the harvest area was 7,100,000 hectares or 25% of the global acreage. As to yield, our country is among the 10 TOP producers, with a yield of 2.46 t/ha, being only behind Hungary (2.81 t/ha) and France (2.76 t/ha) [2]. However, the high economic efficiency of the crop leads to the oversaturation of crop rotations with sunflowers and the evolvement of new virulent races of many pathogens of infectious diseases [3]. As the phytosanitary condition of sunflower fields is worsened, new trends in breeding, which require comprehensive studies of the crop biology and its pathogens, are developed [4].

Due to the climate instability, non-observance of at least the basic requirements for crop rotation and the crop cultivation technology, insufficient amount of sowing equipment, improper attitude to seed quality, neglect of hybrid selection, aand disease-inflicted damage of fields, the biological potential of sunflower in our country is only 50% [5]. This indicates an insufficient knowledge of the peculiarities of sunflower cultivars' and hybrids' responses to stressful growing conditions as well as of prevalence and development of diseases and pests on the crop [6].

Research into the prevalence, development, and harmfulness of major diseases of sunflower, determination of the species composition of pathogens, description of morpho-biological features of pathogens, and optimization of existing measures to protect the crop against diseases are prerequisites for the creation of highly productive hybrids [7].

The world scientific practice shows that agricultural crop breeding for resistance to diseases and protective measures should be based on a deep knowledge of the pathogen nature and development, symptoms and harmfulness of the disease [8].

Diseases of agricultural crops cause significant damage to plants, sharply reducing yields and deteriorating product quality. A successful solution to the problem of sunflower resistance to diseases can be achieved due to understanding the general theory of this crop immunity, creating a genetic basis for the breeding of hybrids and cultivars with complex resistance, and optimizing the current protection measures. A significant role is cast to the elaboration of objective predictions of the development of economically significant diseases and effective methods of their diagnostics [9].

Therefore, the creation of pathogen-resistant sunflower hybrids and cultivars is one of the breeding mainstreams [10].

The common sunflower (Helianthus annuus L.) is a species of the class Dicotyledones, the daisy family Asteraceae L. [11]., genus Helianthus L. [12]. The genus Helianthus L. is extremely polymorphic. This is reflected in the existing classifications: the number of species, depending on the proposed taxonomy, varies from 10 to 254 [13].

In the middle of the 20th century, the classification developed by Heiser et al. [14] was most widespread; it divided Helianthus L. into 68 annual and perennial species. Later, it was refined and comprised only 49 species, differing in ploidy levels and growth habits [15]. These species are grouped into 4 sections: Helianthus (annual species), Agrestes (one annual species), Ciliares (perennial species), and Divaricati (perennial and one annual species).

The approach proposed by the authors to the distribution of the genus Helianthus L. was validated by RFLP assay [16].

The cultivar as intellectual property is one of the important means of increasing the productivity of agricultural crops. It is the state scientific and technical examination of plant varieties that provides for the transformation of a cultivar from a biological object into a specific form of intellectual property, which becomes a product on the market of varieties and seeds. Determination of the criteria for the protectability of a cultivar is the initial stage of the market circulation of the cultivar, regulation of relations between its author (breeder), producer and consumer. Therefore, varietal plant resources reflect the supply of agriculture, forestry, communal enterprises, and food, processing and pharmaceutical industries with cultivars and hybrids of all groups of agricultural crops. Natural plant resources are objects of the plant world that are used or can be used to satisfy consumers' needs. National plant varietal resources are formed within the state scientific and technical examination, which determines the directions of their creation, formation and use [17].

Analysis of recent research and publications. Folk breeding played an important role in the creation of oil sunflower; it created unbranched forms with a significantly increased oil content. In 1853, the oil content in sunflower seeds was only 15%, or 2–4 times less than in other oil crops [18]. The wide polymorphism of the genus Helianthus L. led to a great diversity of sunflower forms. There were mutations during the formation of domestic sunflowers; on the 250-year improving breeding, they contributed to the creation of new starting materials for further breeding. After the first step had been taken to consciously improve biotypes by selecting the best of them, the way for empirical breeding was opened. Intuition, artistic taste, and interest in work became a measure of breeding success [19]. Folk breeding created sunflower forms called 'Zelenka', 'Fuksynka', 'Puzanok', and others, which were widely grown by farmers and can be found in homesteads until now [20]. Planned work at studying and developing scientific breeding of sunflowers was started by three research institutions: Kharkiv Exprimental Station (now the Yuriev Plant Production Institute of NAAS) in 1910, the experimental breeding field Kruglik (now V. S. Pustovoyt All-Russian Research Institute of Oil Crops) in 1912, and Saratov Experimental Station (now the Federal State Budgetary Scientific Institution "Federal Agrarian Scientific Center of the South-East") in 1913. In the 1920s, large-scale work on sunflower biology was started; it became the foundation of scientific breeding. A huge collection of specimens was collected and invstigated; from these specimens, highly productive accessions were bred via individual and mass selections. As a result of the scientific work conducted by Professor B.K. Yenken, the first Ukrainian sunflower cultivar 'Zelenka 76' was created, and cultivar-population 'Kharkivska 22-82' was created at Kharkiv Experimental Station in 1929. From 1920 to 1929, breeding cultivars such as 'Saratovskiy 169', 'Fuksinka Voronezhskaya', 'Kruglyk A41', 'Zelenka Kharkivska 76', and others were grown on private fields [21]. Using the classical method, which was developed by Academician V.S. Pustovoyt, based on individual selection of plants from cultivars and hybrid populations, individual assessments of the offspring, and subsequent targeted repollination of the best families during free flowering in isolated plots, the Yuriev Plant Production Institute of NAAS of Ukraine created and introduced into the production the following cultivars-populations: 'Kharkivskyi 100', 'Kharkivskyi 50', 'Kharkivskyi 101', and 'Kharkivskyi Skorostyhlyi' [22].

A special period in sunflower breeding was devoted to increasing the resistance of plants to various pathogens. Breeding for group immunity is an important objective to improve this oil crop. It is based on artificial mutations in the gene pool, which occur in industrial cultivars, wild forms, and nowadays in the first generation hybrids [23]. In 1950, it was time to use interspecies hybrids to obtain breeding valuable materials that had group immunity. I.I. Marchenko, V.H. Volf, and M.S. Sytnyk in Kharkiv as well as B.K. Pohorletskyi in Odessa launched the creation of interspecies sunflower hybrids using distant annual and perennial species of the genus Helianthus L. [24]. The creation of interspecies domestic sunflower hybrids, which were immune to broomrape, rust, and downy mildew, and yielded a lot, opened the way to originating new cultivars-populations ('Lider', 'Konkurent', 'Berezanskyi', 'Odeskyi 63', 'Rodnik', 'Kharkivskyi 3', 'Kharkivskyi 7', and others), and most importantly, prepared the ground for the creation of lines, which are currently used in heterosis breeding. Climatic changes, extensive introduction of late-ripening cultivars, and increased acreages with violations of crop rotations led to the accumulation of the pathogens of downy mildew, white and gray rots, resulting in almost annual epiphytotics of these diseases [25].

Cultivation of up-to-date sunflower hybrids is one of the main ways to increase yields. They have high yield potentials, are plastic to environmental conditions, highly tolerant to diseases, and highly resistant to lodging and shedding [26].

Breeders of the Yuriev Plant Production Institute (YPPI) of NAAS, both independently and in colaboration with other NAAS institutions, have registered 46 innovative sunflower hybrids (50.5% of the NAAS institutions' innovations, 20% of domestic sunflowers and 5.1% of the total number). These are hybrids bred by YPPI breeders and those created jointly with the Plant Breeding & Genetics Institute – National Centre of Seed & Cultivar Investigation ('Hektor', 'Sibson', 'Kadet', 'Akademichnyi', 'Husliar', 'Charodii'). The diversity of created hybrids in terms of a set of biologically and economically valuable traits and qualities (ripeness groups, high productivity, resistance to major pathogens, quality of raw materials, strong heterosis, genetically determined adaptability to agro-ecological growing conditions) allows compiling full-scale optimal compositions of hybrids for farms in the steppe, forest-steppe and woodlands of Ukraine. The hybrids present the entire range of the diversity of modern sunflower hybrids. They are highly adaptable to growing conditions in all zones of Ukraine, resistant to the most common diseases, and may yield up to 5.6 t/ha. Quality indicators of sunflower varietal resources are presented in the State Register of Plant Varieties of Ukraine Suitable for Dissemination in Ukraine in 2020. A special group consists of hybrids with a high content of oleic acid in oil. Among them, there are hybrids selected by the Yuriev Plant Production Institute of NAAS: 'Hektor', 'Kadet', and 'Oplot' containing 75−85% of oleic acid in their oil. No genetic engineering methods using foreign genetic material were used for their origination [27].

From 1985 to 1995, the State Service for Cultivation and Protection of Plant Varieties of Ukraine included a lot of domestic and foreign hybrids in the State Register of Plant Varieties Suitable for Dissemination in Ukraine. In 2008, the Register had 257 sunflower hybrids, but as of April 2024, there are 1,047 hybrids in the Register. At the same time, the share of domestic hybrids is about 30% [28]. Every year, the Register is replenished with new hybrids, the yield potential of which ranges from 4.2 to 5.0 t/ha. These are well-known hybrids, such as 'Yason', 'Oskil', 'Darius', 'Zorepad', 'Kapral', 'Kvin', 'Boiets', 'Kyi', 'Maksymus', 'Etiud', 'Enei', and others bred in Kharkiv; 'Zhoda', 'Zlyva', 'Odeskyi 122', 'Odol', and 'Soniachnyi' bred in Odesa; 'Zaporizkyi 28', 'Zaporizkyi 32', 'Riabota', and 'Nadiinyi' bred in Zaporizhzhia; 'Tytanik', 'Emperator', 'Prezydent', 'Hena', etc. bred at the Institute of Field and Vegetable Crops (Novi Sad, Serbia) and many others. Recently, Ukrainian breeders from the Yuriev Plant Production Institute of NAAS, the Plant Breeding & Genetics Institute – National Centre of Seed & Cultivar Investigation, and the Institute of Oil Crops of NAAS, have initiated new breeding trends, which are related to the improvement of the fatty acid composition of oil and the resistance of hybrids to imidazole and sulfenylurea herbicides [29].

The state qualifying examination of plant varieties using regulatory, control and advisory mechanisms is the single optimal option to ensure the formation of plant varietal resources and their legal protection and to transform the cultivar from a biological object into a specific form of intellectual property, which becomes a product on the market of cultivars and seeds [30]. The state qualifying examination is activities aimed at investigating, verifying, analyzing, and evaluating the scientific and technical level of examined objects and drawing justified conclusions for decision-making regarding such objects. The main objectives of scientific examination are as follows:

– Objective and comprehensive studies of objects to be examined;

– Verification if examined objects meet the current requirements, regulations, and laws;

– Evaluation if examined objects correspond with the current level of scientific and technical knowledge, trends of scientific and technical progress, principles of the state scientific and technical policy, requirements of environmental safety, and economic feasibility;

– Analysis of using scientific and technical potentials, evaluation of the effectiveness of scientific research and experimental and design developments;

– Prediction of the scientific-technical, socio-economic and environmental consequences of the implementation or activity of examined objects;

– Preparation of scientifically sound expert opinions. The main principles of scientific and technical expertise are the competence and objectivity of the persons, institutions, and organizations conducting examinations;

– Taking into account the global level of scientific and technical progress, norms and rules of technical and environmental safety, requirements, standards, and international agreements;

– Objective assessment of public opinion on examined objects;

– Responsibility for the reliability and completeness of analyses, the validity of the experts' recommendations. The state qualifying examination of sunflower is a joint work of the breeder, the applicant, the Ukrainian Institute of Examination of Plant Varieties, and the State Variety Service. This work requires scientific approaches, high qualification levels, and special responsibility [31].

Recently, the toolkit of breeding methods, which are widely used in creating a sunflower cultivar or hybrid, has been significantly enriched. This ensured the intensive development of sunflower breeding and led to a considerable growth and renewal of its varietal resources. The state qualifying examination is the final stage of the breeding process, at which the best forms (cultivars, hybrids, lines, populations) are formally approved as superior to the current reference accessions in terms of quantity or quality of products or agronomic parameters of plants, including resistance to diseases and pests, and other important features. Use of sunflower cultivars and hybrids with genetically determined levels of adaptation to pedo-climatic conditions of cultivation zones is one of the most effective and economically profitable ways to provide agribusiness with oil-fat raw materials.

An effective gain in yields is based, first of all, on achievements of breeding institutions and breeders as the main link in the creation of new cultivars and expert evaluation of cultivars in the state trials for adaptability to biotic and abiotic factors, suitability for existing farming techniques, and economically valuable characteristics, which determine yield amount and stability as welll as energy and economic feasibility of cultivation [32].

Today, the state qualifying examination of sunflower is carried out in 2 directions: field studies of cultivars for suitability for dissemination and examination for meeting the protectability criteria (distinctness, uniformity and stability (DUS) tests) [33].

The method by which sunflower cultivars and hybrids are tested for meeting the protectability criteria was developed in accordance with the recommendations of the International Union for the Protection of New Varieties of Plants (UPOV) and includes 2- to 3-year field examinations with identification of 42 morphological features during different phases of plant development [34].

Fifteen state variety testing centers and variety stations investigate and determine if sunflower cultivars and hybrids are suitable for dissemination: 5 in the forest-steppe and 10 in the steppe zone. Among the scientific institutions of our country, the largest breeding work on sunflower is carried out at the Yuriev Plant Production Institute of NAAS, the Plant Breeding & Genetics Institute – National Centre of Seed & Cultivar Investigation, and the Institute of Oil Crops of NAAS [35–40].

In recent years, Ukrainian sunflower hybrids have come much closer to foreign hybrids in terms of economically valuable characteristics. In 1996, foreign hybrids yielded on average 6.6 t/ha more than Ukrainian ones, but in 2006, the difference was was 2.9 t/ha and this positive trend is maintained nowadays [41].

Setting the task. Over the past 20 years, the total production and yields of major agricultural crops have increased by 20–38% in the world. Considering that at present, lives of about 40% of the world's population depend on agricultural products as a means of livelihood, the yields of major field crops have to be doubled. By 2030, the global population is expected to grow by 2 billion and exceed 9 billion, resulting in an approximately 35% rise in food demand.

Nowadays, pesticides are widely used around the world to prevent the harmful effects of pathogens on plants and, as a result, to increase the yields of agricultural crops. Although these chemical compounds make it possible to significantly reduce the harmful effects of diseases, pests, and weeds on agricultural crops, they have a considerable negative impact on the environment and eventually on the human body [42].

Pesticides (from the Latin pestis (plague) and caedere (kill)) are chemicals used in agriculture and horticulture to control pests (harmful or unwanted microorganisms, plants and animals). They are chemical compounds that are used to protect plants and agricultural products as well as to control carriers of dangerous diseases.

Pesticides are spread in the environment both physically and biologically. The first way is dispersion by wind in the atmosphere and spread by water. The second one is transfer by living organisms through food. As organisms move up the food chain, concentrations of harmful substances increase, accumulating in visceral organs, mainly in liver and kidneys.

Pesticides, getting into the human body and accumulating there in large amounts, lead to the development of acute poisoning and many chronic diseases and increase in the number of congenital abnormalitis and child mortality. Another negative property of pesticides is that they can be excreted from the body and transferred to babies through maternal milk.

Pesticides are not only very toxic but also rather stable substances. The stability of pesticides is compared with radioactive isotopes and is also evaluated by half-life (the time required for a 2-fold decrease in the concentration of a pesticide). Organochlorine pesticides are the most resistant ones. Pesticides made from plants, such as pyrethrum (a natural insecticide), are considered the most dangerous. Pesticides cause many problems related to pollution, because when sprayed, they can get into the surrounding area and on people, accumulate in soils and plants.

Systemic fungicides, which resistant to washing off from plants, are gaining particular importance. Incorrect application of them can cause great damage to crops, the environment, human health, domestic animals and poultry. At the same time, in many instructions, the doses of agents range widely, for example, 1–2 kg/ha.

Application of high doses of fertilizers can worsen product quality and groundwater condition, polluting nearby rivers and reservoirs. Mineral fertilizers could boost crop yields to a certain extent, but a further increase in their doses did not increase yields, which was associated with decreased reserves of humus in soil. Yields cannot be increased without improving fertilizer application technologies. Uncontrolled aplication of fertilizers leads to environmental pollution, threatening human health.

Improper or excessive use of pesticides is especially dangerous. Notably, some of them are transformed, that is, new toxic substances appear (secondary toxicity). It is impossible to assess all the consequences of exposure to pesticides due to inadequate methods of testing.

When carefully studied, all pesticides, without exception, had either mutagenic or other negative effects on wild-life and humans. Modern organophosphate pesticides, which quickly decompose, can cause depression, irritability, memory disorders, and other neuromental disorders. About 90% of fungicides, 60% of herbicides, and 30% of insecticides are carcinogenic.

So, chemicalization, which is intensively developed in agriculture, can be evaluated from two positions: as economically beneficial and as ecologically dangerous for the environment and for humans. Intensive pollution of the environment is largely a consequence of irrational farming [43].

Through the lens of the above-said, the issue of growing high-yielding cultivars and hybrids of agricultural crops, which are resistant to harmful organisms and require minimal treatment with chemicals, due to their high performance, arises acutely.

Ukraine is among major countries that have opportunities to increase croppages due to genetically increased yield capacity of new cultivars and hybrids, an integrated approach to technological operations, introduction of new technical equipment, optimization of plant protection measures, etc. At the same time, the main attention should be focused on the creation of new cultivars and hybrids of agricultural crops, which would be highly productive, adapted to growing conditions, and resistant to pathogens and pests. It is known that in Ukraine the annual shortfall in crop production because of the harmful effects of pathogens and pests is 12–14%, which is equivalent to the cost of wheat grain from 1 million hectares. In their practice, breeders of our country use immunologists' theoretical achievements in elucidating the mechanisms of plant resistance . The rapid development of biotechnology and genetic engineering makes it possible to modify individual genes, use genes from species that are not able to interbreed, obtain homozygous material from haploids en masse, etc. Outstanding breeders of the National Academy of Agrarian Sciences of Ukraine, i.e. S. F. Lyfenk, M. A. Lytvynenko, A. A. Linchevskyi, M. R. Kozachenko, B. V. Dziubetskyi, L. V. Kozubenko, V. V. Kyrychenko, M. V. Roik and others, achieved significant success in breeding high-yielding, immune cultivars, lines and hybrids of major field crops. The authors believe that no breeder can achieve desirable results without knowledge of the immunity genetics basics and methods of targeted selection of breeding material against infection backgrounds [44].

Presentation of the main research material. At the beginning of the 20th century, scientifically based plant breeding for disease resistance was initiated. Back in 1907, Professor A. A. Yachevskyi, one of the founders of domestic phytopathology, noted that the practical use of disease-resistant plants should be the mainstream in plant protection. Successful breeding to create resistant cultivars and hybrids became possible owing to the development of a new science – genetics and its separate section – genetics of immunity [45].

The gene-for-gene model proposed by an American phytopathologist, H. H. Flor, and the vertical and horizontal resistance concepts articulted by Van der Plank have become important theoretical bases for plant breeding for resistance to diseases. According to Flor, for each gene controlling resistance in the plant, there is a corresponding, specific gene controlling virulence in the pathogen [46].

In order to determine the most potentially dangerous forms of phytopathogens, for which assessments of starting and breeding materials are required, it is necessary to monitor the pathogenicity of pathogens and and how it changes in locations where cultivars and hybrids are grown. The success of breeding depends to a large extent on the awareness of this issue, in particular, the cultivars' resistance duration.

The intra-population structure – race, biotype, and strain composition of pathogens in a certain region – is determined by phytopathologists, who analyze pathogen populations in fields intended for different purposes: production (cultivars included in the Register), state trials (cultivars-to-be), breeding institutions' experiments (collection and breeding accessions). To determine the virulence (pathogenicity) of pathogen isolates, appropriate sets of test cultivars or isogenic lines are used. To elucidate if an isolate belongs to a certain physiological race or biotype, appropriate clues are used; to find if an isolate belongs to a known strain, there are appropriate scales [47].

In a complex with state-of-the-art ways of plant protection, all of the above gives a positive outcome in terms of reducing the harmfulness of pathogens on domestic plants and, as a result, the yields and performance of the latters are increased [48].

Sunflower is a major oil crop in the world; it is grown on almost all continents. Its economic importance for oil production is relatively young – about 150 years [49]. Considering the great economic importance of sunflower, a huge step has been taken in investigations of the crop biology, sunflower breeding and cultivation technologies for over 100 years of research. On the territory of major sunflower-breeding countries, domestic forms with an oil content of 47–53% were bred from local forms with an oil content of 28–30% [50].

Breeders , Shcherbyna V. I., Romaniuk H. T. Prokhorov K. I., and others successfully worked on creating resistantm higher-yielding sunflower cultivars [51].

Today, the commercial sunflower production in the world has reached more than 35,000,000 tons [52], which is largely attributed to successes in the breeding of hybrids. The global acreage amounts to 25,230,000 hectares, with Ukraine and Argentina being the leaders in sunflower production, as their share exceeds 80%. The sunflower oil production in the world has grown sharply in recent years and exceeded 36,000,000 tons, including about 11,000,000 tons in Ukraine in 2013. It is common knowledge that Ukraine has taken the first position in the global oil production. In 2023–2024, 5,800,000 hectares were sown with sunflower in Ukraine [53–54].

The onset of the extensive development of hybrid sunflower breeding was associated with the discovery of cytoplasmic male sterility by Leclercq P. in 1969 [55–56]. In a very short period, success was achieved in the creation of inter-line sunflower hybrids, which showed advantages compared to cultivars. Compared to hybrids of the first half of the 1970s, modern sunflower hybrids yield 15–20% more and the oil content in their seeds was increased by 10–14%, confirming the considerable results of heterosis breeding of the crop. Results of studies in sunflower breeding, physiology, genetics, biology of ontogenesis, and cultivation technologies, which contributed to the formulation of the theoretical foundations of breeding, are covered in several monographs and articles [57–61].

Along with Ukraine, a significant development of sunflower breeding and cultivation of sunflower hybrids has been noted in many countries worldwide, in particular, in Yugoslavia [62], Romania [63–64], France [65], Bulgaria [66], Hungary [67], Argentina [68], USA [69–70].

Heterotic sunflower breeding has a relatively short history and its success is directly related to the theoretical principles underlying its technology. A number of publications [71–73] were dedicated to solving the challenges of selecting starting materials and developing evaluation methods to create highly heterotic combinations.

The mainstreams in the breeding of heterotic sunflower, as with other crops, are breeding for high yield capacity and quality and the other directions ensure achieving these objectives. Currently, the genetic potential of hybrids, depending on ripeness groups, varies from 3.3 to 5.5 t/ha; the oil content is supposed be at least 48%, mostly 50–51%. Agrometeorological conditions determine the possibility and expediency of growing hybrids of different ripeness groups: from ultra-early to medium-ripening. To fulfill its potential, the hybrid should be resistant to environmental stressors: drought and significant temperature fluctuations.

Breeding for disease resistance is also the most important prerequisite that ensures harvesting yields. Breeding for manufacturability requires sunflower hybrids with optimal height, breakage-resistant, with quick drying of seeds. Recently, leading breeding institutions have been working on creating hybrids that would be resistant to imidazoline and sulfonylurea herbicides. The creation of hybrids with various fatty acid composition of oil is a special trend in breeding for quality. Nowadays, sunflower hybrids with increased and high content of oleic acid in oil are widely grown worldwide [74].

Since 2000, international conferences have been held every 4 years: the 15th was held in France in 2000, 16th – in the USA (2004); 17th – in Spain (2008), and 18th – in Argentina (2012). The main attention at the conferences was focused on the development and improvement of theoretically oriented methods of research and creation of starting materials for breeding. In particular, at all conferences and seminars, the issues of genomics, mapping, and molecular markers to identify starting materials by disease resistance and the challenges of forming genetic collections and studying the gene pool of wild relatives of sunflower were prioritized [75–77]. Separate seminars and conferences were devoted to the problems of resistance to pathogens: in China (Beijing, 1996), USA (1998), Moldova (Chisinau, 2011) [78].

Breeding is a scientific and information-intensive technology of creating biological means of production – cultivars and hybrids [79]. According to the definition of M. I. Vavilov, breeding is a complex science that integrates all scientific knowledge about the object of breeding, the physical and biotic environment of the cultivation site in accordance with the requirements of production. Since the theoretical conceptualization of the problems of breeding as a science made by M. I. Vavilov in the 1930s, there has been a period of rapid development of all sections of biology. There has been a change in priorities in agronomic sciences; scientific disciplines that reveal the physical nature and mechanisms of systemic processes have been also developed. An important place in this is given to computer technologies that provide opportunities for a new and novel organization of information support for breeding [80].

Currently, the focus has been the development of general theoretical concepts for understanding the nature and mechanisms of biological phenomena and processes based on the integration of acquired knowledge in different fields of science. This is related to developing methodologies of systemic research, systemic analysis, and computer technologies. The formulation of general theories of ontogenesis, development, and genetic organization at different levels of biological organization made it possible to develop the theory of breeding [81–83].

Increased yields, primarily due to growing hybrids that are maximally adapted to environmental and production conditions, remain the most effective way to enhance production. Scientific research and practice show that the fulfillment level of the biological potential of modern hybrids fluctuates significantly over the years, averaging 50–60% [84].

The creation of sunflower hybrids, maximally adapted to current environmental and production conditions, potentially yielding 4–5 t/ha, remains the mainstream in the coming years [85–86].

Regular breeding of sunflowers in Ukraine was initiated at Kharkiv Experimental Station (now the Yuriev Plant Production Institute of NAAS) way back in 1910. In the 1960s, V. H. Volf's, O. M. Riabota's, and others' works gave a significant impetus to heterosis breeding [87–88].

Sunflower breeding has gone from populations to heterosis; significant theoretical and practical achievements have been obtained.

The mainstreams in the sunflower hybrid breeding conducted by originators [89–90] can be categorized as follows: high yield capacity, growing period length, resistance to abiotic factors, resistance to diseases and pests, manufacturability during the harvest period, high content of oil, high contents of certain fatty acids, resistance to herbicides, pollen viability, high content of nectar, etc. [91]. However, there are other trends, without which it is impossible to breed the ideal hybrid that from year to year produces stable yields, with top-quality indicators, necessary for processing enterprises of Ukraine. This is a morphophysiological type of hybrid; such characteristics as intensive initial growth, anthesis length, leaf area, plant and head structures, seed type, and others, which are supposed to be different for different climatic zones, are of particular importance [92].

Thus, the review of foreign and domestic literature allows us to conclude about significant achievements in studies of sunflowers as breeding objects and considerable practical results in the creation of hybrids in a relatively short time. Along with this, at the current stage, the improvement of the theoretically justified heterosis breeding technology using knowledge about the breeding object as a biological system is a defining factor. This causes the need for in-depth research and generalizations on the problems of the breeding theory and practice, using results of different branches of biology and organizing informational support for the breeding process [93].

Even with a complete supply of sunflowers with macronutrients, it is impossible to harvest a proper yield without a balanced supply of trace elements. At the initial stage of development, iron, zinc, magnesium, and manganese are vital elements for this crop; somewhat later sunflowers respond acutely to problems with boron, copper, molybdenum, and sulfur [94]. In the crop seed production, the low productivity of parental forms, which prevents the rapid introduction into the production of new hybrids of different ripeness groups, intended for different purposes, is a considerable challenge. Since top-quality seeds are an important component of increasing the productivity of parental forms of sunflower hybrids [95], along with genetic-breeding methods, the development of technological methods for solving this problem is no less important. Such technological methods include, for example, stimulating growth and reproductive processes and boosting the resistance of sunflower plants to various harmful factors via differentiated application of microfertilizers and growth regulators at different stages of the crop ontogenesis [96].

First of all, top-quality seeds are an important component of increasing the productivity of parental forms of sunflower hybrids. Growth regulators can influence the most important processes in the plant in a targeted manner and mobilize the potential capacities of the genome [97–100]. Enhanced resistance of plants to pathogens and abiotic factors as well as increased yields are important aspects of the action of growth regulators [101].

Plant growth regulators are natural or synthetic organic substances capable of stimulating or inhibiting the growth and development of plants without killing them. Natural growth regulators, phytohormones, are synthesized in plants in small quantities and necessary for their vital activity. Synthetic plant growth regulators are widely used as retardants – substances that slow down the growth of plants but at the same time strengthen their stems. This is especially important to prevent crop lodging under waterlogged conditions [102–103].

In the context of the introduction into production of new growth regulators and new highly productive sunflower hybrids, the effects of the above-mentioned technological components on the leaf, root, and yield formation have not been thoroughly studied; so this issue is of scientific and practical interest. The solution to this problem consists in optimizing the performance of the valuable oil crop, introducing into the sunflower cultivation technology of plant growth regulators, which protect sunflower seeds in case of prolonged exposure to adverse factors, activate the development of the root system, enhance cellular respiration, stabilize the vital activity of useful soil microflora, increase effectiveness of pesticides and, as a result, increase yields of the oil crop. However, there are currently few data on the effects of different plant growth regulators on sunflowers, and, moreover, they are often contradictory [104]. At the same time, it is known that these agents affect hormonal regulation, which determines the course of the most important physiological processes. In particular, they accelerate the formation of new plant organs, anthesis onset, and ripening of seeds [105–110].

The application of plant growth regulators, such as Treptolem, Radostim, Vermiiodis, Noostim, Dominant, biologic Polymyxobacterin, and microfertilizer Quantum in the propagation of sunflower seeds is an effective technological measure that allows enhancing the production of seeds and thus accelerating the introduction of new hybrids into production, concurrently increasing yields of hybrid seeds. The effectiveness of this measure depends on agents, methods of their application, varietal characteristics of sunflower forms and hybrids, and meteorological growing conditions [111].

Anishyn L.A. noted that Emystim C significantly intensified the processes of respiration, nutrition, photosynthesis, and chlorophyll accumulation in leaves [112]. Yeremenko O.S. showed that plant growth regulator Vympel increased the sunflower leaf surface during anthesis on average by 14.1% and regulator AKM increased it by 33.1% compared to the control [113–114]. Cherkasy Experimental Station and Matsebera A.H. reported that biostimulants enhanced metabolic processes in the plant and improved energy exchange, resulting in 4- to 11-fold increased field resistance of plants to diseases [115].

The introduction of energy-saving and ecologically safe technologies into the production at different stages of the ontogenesis of sunflower parental components allows for a 12–17% increase in the production. The cost of seeds of sunflower parental components obtained thanks to such technologies can vary from 9,000 to 12,000 UAH/ha, depending on yield, and the cost of their application only ranges within 80–200 UAH/ton of seeds or 40–100 UAH/1 ha [116–117].

Conclusions and proposals. The use of plant growth regulators is an important element of ecologically safe resource-saving technologies for growing different agricultural crops, helping to increase their yields and product quality [118–120]. Due to the high biological activity of regulators in plants, major vital processes are activated. As a result, green mass and roots grow more rapidly; hence, nutrients are used more actively and the protective capacities of plants are boosted, primarily the resistance of plants to adverse environmental factors (high and low temperatures, water deficit, phytotoxic effects of pesticides, damage by pests and diseases). This allows, in particular, for a 20% reduction in amounts of applied dressers and fungicides without weakening the protective action, which is very important in state-of-the-art breeding [121–125].

In economically developed countries, the scope of introduction of growth regulators of different origins into agriculture is expanding [126–133]. NAAS of Ukraine draws attention to the need to study the effects of plant growth regulators to raise the effectiveness of breeding, enhance heterosis of hybrids, improve the primary seed production of agricultural crops, and increase the economic qualities of seeds [134]. Our state does not lag behind foreign colleagues and a similar trend is gaining momentum in Ukraine [135–138].

So, the review of publications revealed a rapid increase in the sunflower acreage in Ukraine. Current trends in the crop breeding to achieve high yields are outlined; among them, resistance to diseases and optimization of protection measures take the leading positions.

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