UDC 631.1.60

STUDY OF WINTER WHEAT COLLECTION FOR DEVELOPING INITIAL MATERIAL WITH LOW CD-UPTAKE

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Winter wheat is the leading crop in Ukraine and the world and provides the human food needs. The leading breeding institutions of Ukraine are studying wheat collections, which makes it possible to identify sources and donors of necessary breeding traits and involve them in hybridization. For a systematic and successful hybridization programme a thorough understanding of genetic architecture of plant yield and other important economic characters must be achieved. One of the current areas of breeding work is obtaining the source material with low ability to accumulate heavy metals, in particular cadmium. The accumulation of cadmium in the soil leads to its absorption by the root system of plants and intaking in the vegetative and generative organs. Among the crops that have a high ability to actively accumulate cadmium, winter wheat is one of the first places. The minimization of Cd pollution in wheat grain is urgently needed. In many countries technical solutions for decreasing wheat grain cadmium are elaborated. In particular, the methods of conventional breeding (selection, hybridization, pure lines) are used. One of the possible ways to solve this problem is to create breeding varieties, which are characterized by low ability to accumulate this heavy metal The aim of the study was to establish the breeding value of the collection genotypes of winter wheat of various origins on the base of morphological and productivity traits, isolating and developing on this basis the initial material for breeding. Field experiment was carried out in the research field of Sumy NAU. There were selected 41 varieties representing 7 major breeding centers of wheat in Ukraine. Growth parameters (height) and leaf surface area were analyzed in the wheat varieties. These traits were related to productivity parameters such as 1000 seed weight, grain weight per ear and yield.

Based on the collection analysis, wheat samples, which, along with high yields, had a low Cd uptake (less than 1.2 mg/kg. were isolated. This group includes varieties of Okhtyrchanka Juvileina, Svitanok Myronivskyi, Melody Odes'ka, Kubok, Zorepad, Ovidiy, Shchedra Nyva, Oktava Odes'ka and Slaven. These samples are planned to use for further breeding process.

Key words: *winter wheat, collection, valuable breeding traits, low Cd-uptake, initial material.*

DOI https://doi.org/10.32845/agrobio.2022.1.1

Introduction. Creation of sources and donors of selectively important traits, the organization of selection work is based mainly on the world's genetic resources or collections of cultivated plants. Winter wheat is the leading crop in the world as well as in Ukraine and provides the human food needs (Curtis et al., 2002; Lollato et al., 2019; Shewry&Hey, 2015).

Nowdays in the State Register of Plant Varieties, there are more than 460 cultivars of winter wheat. For effective breeding work, the initial material must be studied in detail to meet specific parameters and requirements. The leading breeding institutions of Ukraine are studying wheat collections, which makes it possible to identify sources and donors of necessary breeding traits and involve them in hybridization (Colla & Mackill, 2008; Forster et al., 2014; Hao et al., 2006).

For a systematic and successful hybridization programme a thorough understanding of genetic architecture of plant yield and other important economic characters must be achieved. Thanks to the successful work on the collection study, wheat samples with a high level of homeostaticity, wide adaptability, group resistance to diseases and with high yield were isolated (Dutta et al., 2015; Slafer et al., 2014).

One of the current areas of breeding work is to obtain a source material with low ability to accumulate heavy metals, in particular cadmium. The minimization of Cd in wheat grain is urgently needed in different regions of the world. (Surabhi, 2015) In many countries technical solutions for decreasing wheat grain cadmium are elaborated. One of the possible way to solve this problem is to create breeding varieties, which are characterized by low ability to uptake this heavy metal (Yue et al., 2018; Zaid et al., 2018).

The aim of the study was to establish the breeding value of the collection genotypes of winter wheat of various origins on the base of morphological and productivity traits, isolating and creating the initial material for breeding. There were studied 41 varieties representing 7 major breeding centers of wheat in Ukraine.

Materials and methods. Field experiment was carried out in the research field of Sumy NAU, which according to the zonal distribution belongs to the north-eastern Forest-Steppe of Ukraine. The predecessor was peas.

Sowing term was the second decade of September. The study of collection samples was performed according to common methods. Number of repetitions – three times, area of plot was 15 m^2, placement of plots were consecutive. To solve the tasks phenological observations of plant growth and development, accounting of crop density, plant survival, determining the structure of the crop were carried out according to the "Method of state varietal testing of crops" (Volkodav, 2003). Statistical analysis of yield data was performed using computer programs Microsoft Exel, "Statistica" by the method of variance and correlation analysis.

Results. On the basis of winter wheat varieties grown in the production conditions of the north-eastern Forest-Steppe of Ukraine, the formation of a working collection was carried out. It was based on passport data and the study results at the demonstration site of the Institute of Agriculture of North-East. There were selected 41 varieties representing 7 major breeding centers of wheat in Ukraine, namely: Selection Genetic Institute National Center for Seed Research and Variety Studies (Odesa); Institute of Crop Science named after Yuriev (Kharkiv); Institute of Agriculture (Kyiv); Bila Tserkva experimental breeding station (Bila Tserkva); Institute of Irrigated Agriculture (Kherson), Myronivka Institute of Wheat named after Remeslo, (Myronivka), Ivanivska experimental breeding station (Ivanivka village, Sumy region).

The collection structure of winter wheat varieties according to the originators is presented in Fig.1.

The group of varieties created at Institute of Breeding and Genetic was the most represented in the collection – 17 or 41%. Varieties of the Institute of Crop Science accounted for a high share in the collection – 6 (15%). Ten or less percent accounted on the varieties of the Institute of Soil Science – 4 varieties and Myronivka Institute of Wheat and Ivanivska Research Station for 2 varieties, respectively.

An important characteristic of varieties is the range of their variability in the main indicators of vegetative and generative development, especially plant height, leaf surface area, grain weight from the ear and crop yield.

Plant height is an important agronomic trait for growth and grain yield formation in wheat. Varietal characteristics of crop affected plant height.

This parameter is associated with lodging resistance, growth in the grain number per ear and an improvement in the yield index and thus an increase in grain yield and its quality. To understand relation of different traits to plant height can help breeders select valuable traits more effectively.

The collection structure by plant height is presented in Fig. 2 (2018–2021).

The average value of the indicator was 89.1 cm. The highest values of the average height (more than 1.0 m) were observed in the varieties of Okhtyrchanka Juvilejna (10), Pylypivka Odes'ka (19) and Zaotar (18). The maximum value of the average height was observed in the Rusyava variety (34) – 119.4 cm. Svitanok Myronivskyi had the lowest value of 64.1 cm (12). Statistically significant lower values of this indicator (compared to the average for the collection) were characteristic of the varieties Rozkwit (20), Krugozir (39) and Hurt (9).

The photosynthetic surface of both the whole plant and its individual parts is of great importance in the productivity of winter wheat. When creating a hybrid source material, along with the elements of productivity, the formation of the leaf surface is important. Figure 3 shows the structure of the collection according to the index of the crop leaf surface (LSC). In general, this parameter characterizes the ability of the crop to form and maintain optimal leaf surface per unit area. It is currently believed that for most varieties of winter wheat focused on the Forest-Steppe zone, the optimal value of the LSC is 3–4 m^2 / m^2. The formation of higher values of the index, as a rule, requires a change in the relationship between groups of chlorophyll in the direction of shade-tolerant chlorophyll "b". In other cases, the increase in the values of the indicator (due to increasing the crop density or rates of mineral fertilizers) is accompanied by deterioration of the phytosanitary condition of crops and reduced efficiency of photosynthesis.

The average value of the index was 3.48 m^2/m^2, changing from 1.68 in the Zdobna variety (25) to 6.38 in the variety of Alliance (3).

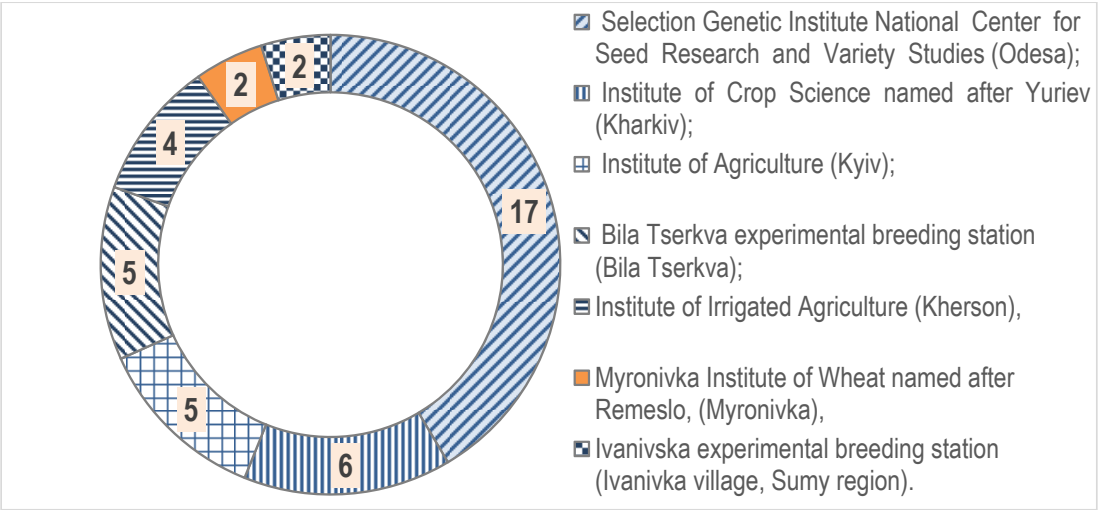
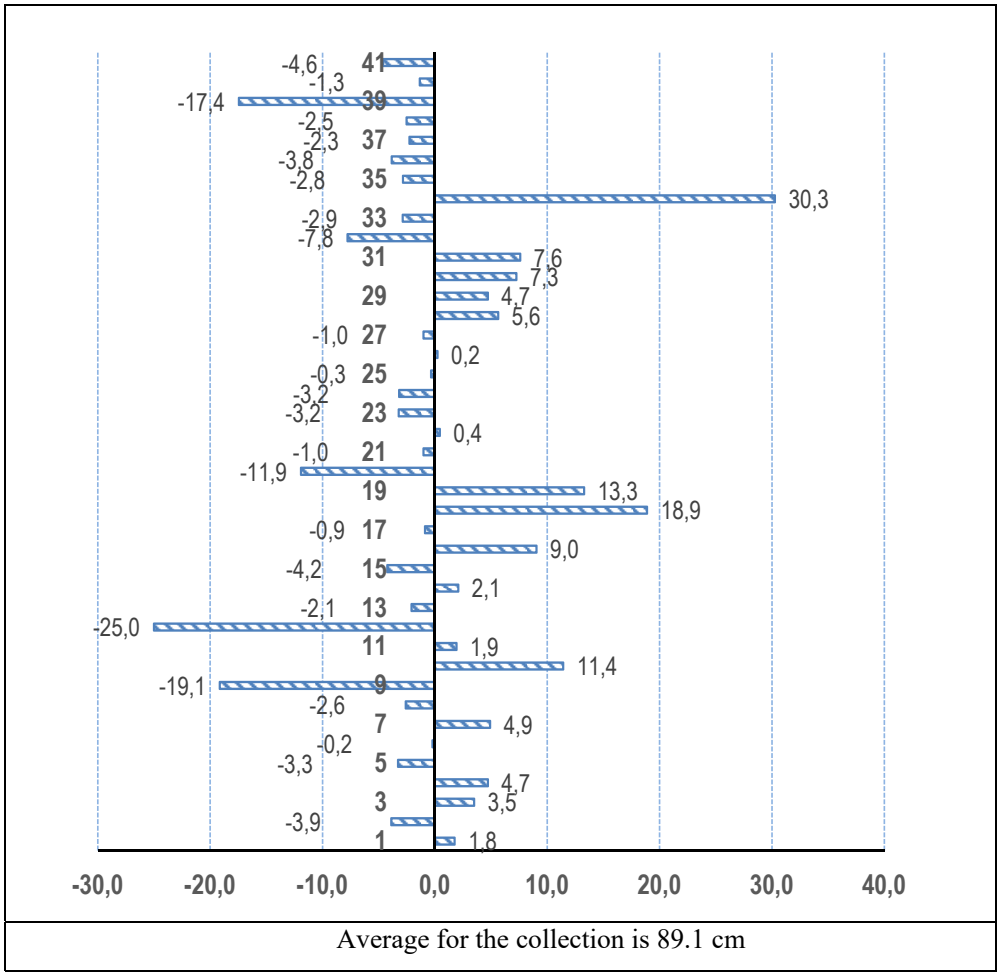
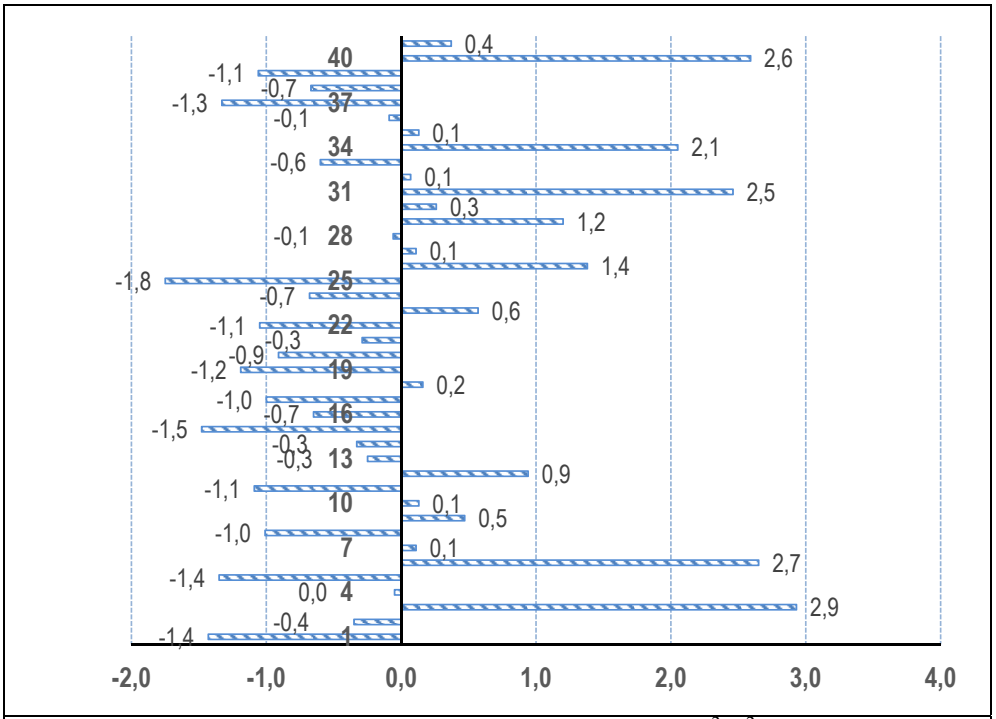


Fig. 1. The collection structure of winter wheat by originator institutions



Average for the collection is 89.1 cm

Fig. 2. The collection structure of winter wheat varieties on the base of plant height



Average for the collection – 3,48 м^2/м^2

Fig. 3. The structure of the collection of winter wheat varieties according to the index of the crop leaf surface

One of the main selection-controlled parameters of winter wheat is the mass of seeds per ear; it combines the number of seeds and 1000 seeds weight. Taking into account the insignificant level of phenotypic variation of both traits due to their rigid genetic fixation, the characteristics of the collection of varieties, as a rule, involve the identification of groups with different schemes for realizing the genetic potential of plants. At the average value of the ear productivity index for the collection at the level of 1.21 g, the maximum values were observed in the varieties of Zdobna (25), Oberig Myronivskyi (17) and Osayna (8). In all cases, high values of productivity were provided above the average values of both components. On the contrary, the minimum values were observed in the Hurt (9), Melody Odes'ka (13) and Rozkvit (20) varieties due to a significant decrease in one of the structural indicators of productivity.

Grain yield is a complex trait and it is highly influenced by many genetic factors and environmental fluctuations. A successful selection depends upon the information on the genetic variability and association of morpho-agronomic traits with grain yield.

A generalizing sign of variety breeding value is productivity. Analysis of Figure 5 shows that the average yield of the collection over the years of research was 6.54 t/ha, changing from 5.34 for the Klad variety (22) to 8.04 t/ha for the Khvala variety (23).

Significantly higher (average in the collection) yields were observed in varieties of Alliance (3), Vidrada (7), Okhtyrchanka Juvileina (10), Svitanok Myronivskyi (12), Oberig Myronivskyi (17), Pylypivka Odes'ka (19), Zdobna (25), Zorepad (28) and Kraevyd (40).

The previous stage of growing winter wheat in the conditions of the analytical background with a concentration of cadmium in the soil of 1.0 g / kg allowed to evaluate the varieties for their ability to uptake this toxic element in the vegetative organs. Data on the cadmium content in aboveground phytomass are presented in Fig. 6. The average cadmium concentration for 41 varieties was 1.40 mg/kg.

The indicator value varied in the range from 2.02 in the variety of Duma Odes'ka (15) to 0.91 mg / kg in the variety of Oktava Odes'ka (37). In addition to the latter variety, the group with the minimum level of cadmium accumulation (less than 1.0 mg / kg) included Svitanok Myronivskyi (12), Melody Odes'ka (13) and Kubok (21). The some varieties also had a statistically lower level of concentration (compared to the average for the collection): Okhtyrchanka Juvileina (10), Zorepad (28), Ovidiy (32), Shchedra Nyva (36), Slaven (41).

The final stage in the formation of the working collection was the creation of groups based on several valuable parameters and assessing the level of intragroup correlations for inter-varietal crossings. According to the peculiarities of spatial distribution of varieties, depending on the values of cadmium content and the main parameters of plant productivity, 2 groups of varieties with minimum values of cadmium content (less than 1.2 mg / kg) were formed (Fig. 7).

A group with cadmium values greater than 1.6 mg/kg was also singled out. The first group "A" includes varieties Okhtyrchanka Juvileina (10), Svitanok Myronivskyi (12), Melody Odes'ka (13), Kubok (21), Zorepad (28), Ovidiy (32), Shchedra Nyva (36), Oktava Odes'ka (37) and Slaven (41).

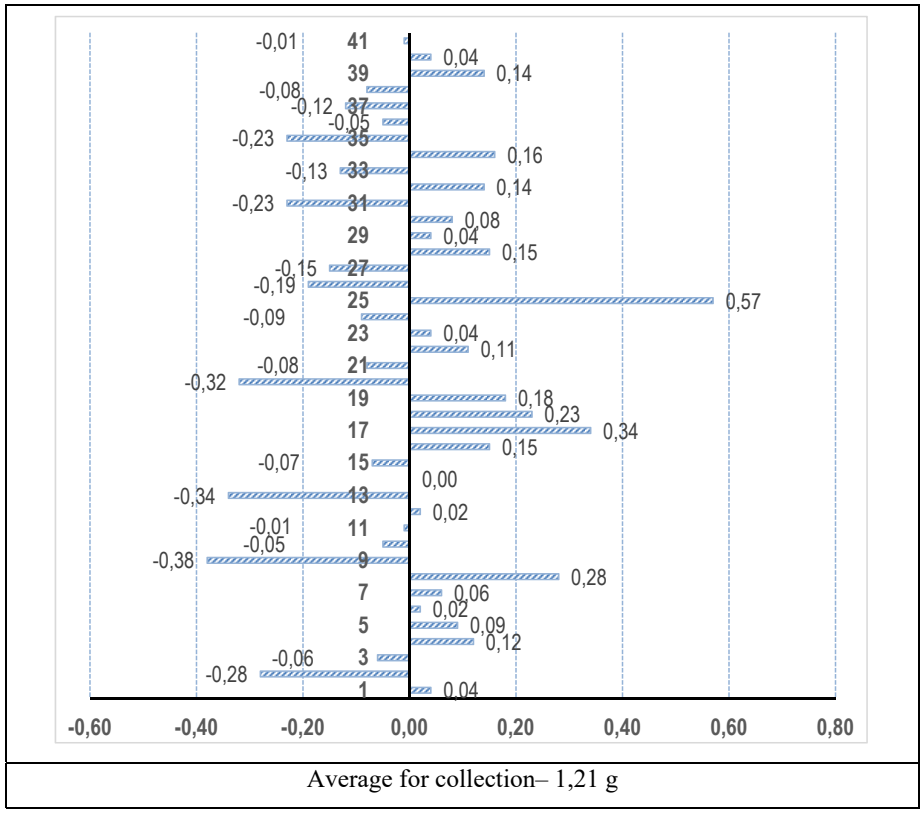


Fig. 4. The collection structure of winter wheat varieties by grain weight per ear, g

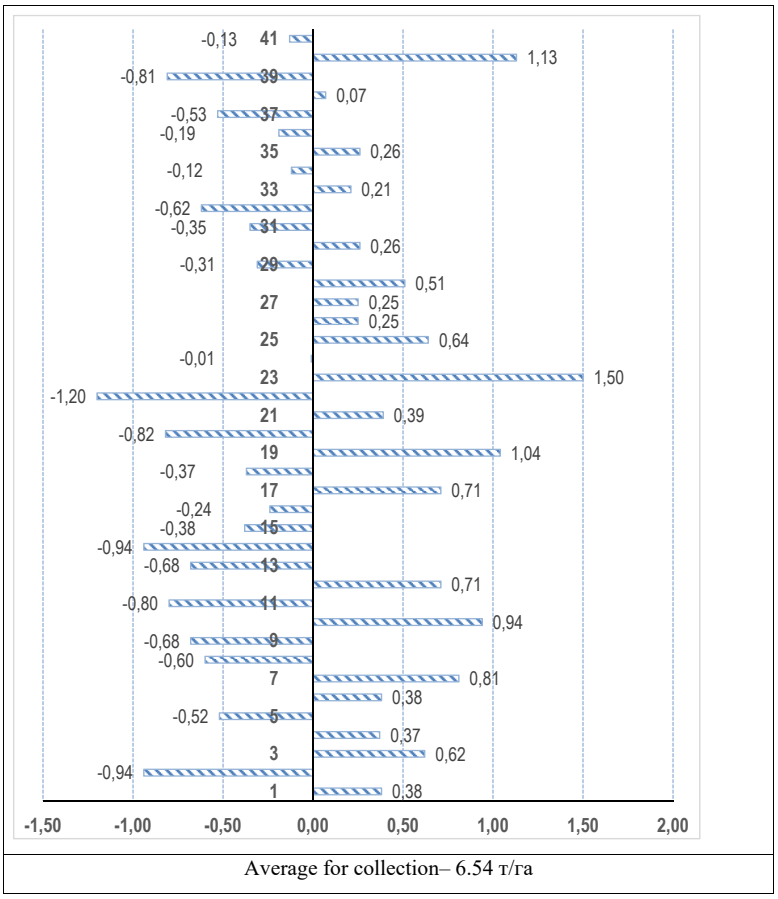


Fig. 5. The collection structure of winter wheat varieties on the base of yield

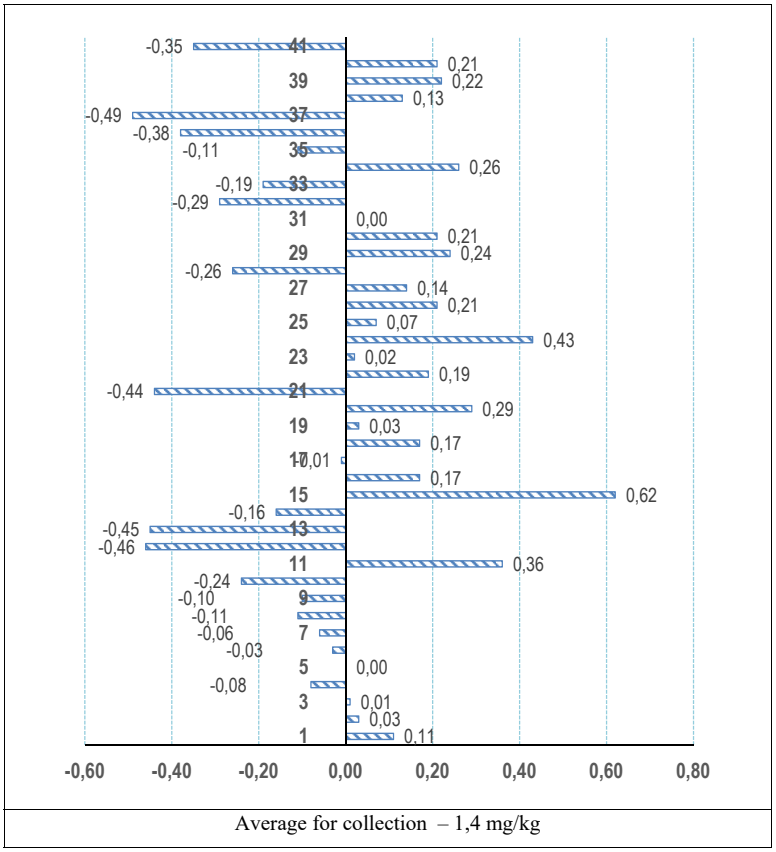


Fig. 6. The collection structure of winter wheat varieties based on the ability of Cd-uptake

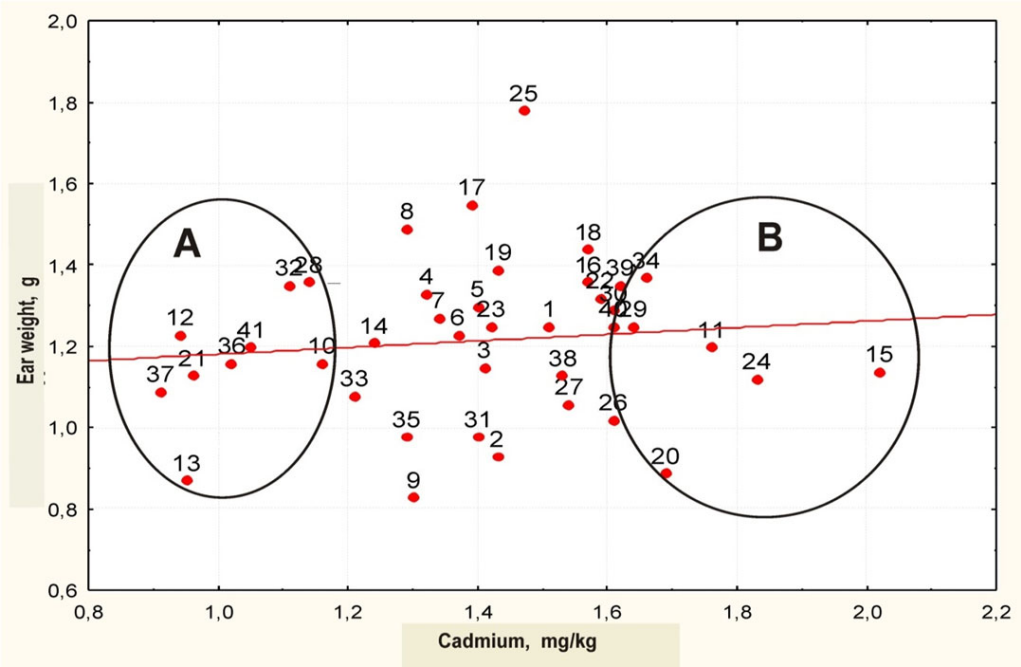


Fig. 7. Spatial placement of varieties based on ear weight (g) and cadmium content, mg / kg: A – group of varieties with low Cd uptake; B – group of varieties with a high level of Cd uptake

Such varieties as Sich (11), Duma (15), Rozkvit (20), Kantata (24) and Rusyava (34) were included in group "B" with the maximum values. It should be noted that some high-yielding varieties, namely 25, 8, 17, 18 and 19 were characterized by average cadmium content (1.3–1.5 mg/kg) and were not included in the crossing groups.

Discussion. Exceeding amounts of Cd in the environment and soil have negative effect on the wheat growth and yield quality. Conversional and molecular breeding approaches for the crop have been developed to minimize Cd uptake and its toxicity. Modern breeding offer number of tools for plant breeding programs that can be used alongside conversional breeding to create low-uptake Cd varieties (Huang et al., 2008; Surabhi, 2011).

The potential of conventional breeding is still an attractive approach to modifying the Cd uptake of wheat varieties. Use of heterosis as well open new perspectives for decreasing wheat Cd uptake and adapting plants to Cd stresses (Ashrafzadeh & Leung, 2016; Hochman, & Horan, 2018).

However, there are some limitations to low-Cd wheat breeding in particular because of its time-consuming. Besides, genetic improvement process is rather slow (Zaid, 2018).

Wheat species and cultivars vary extensively in their ability to uptake, accumulate, and be tolerate to Cd. (Clarke et al. 2002).

Differences in Cd uptake may depend on the adaptation of various genotypes to environmental and production conditions. Low-Cd wheat varieties are the most effective way to reduce risks that are connected with food consumption (Stolt et al., 2010).

Creating of wheat low-Cd varieties and reducing of Cd accumulation in seeds can be realized by both conventional and modern breeding methods. In conventional breeding, low-Cd wheat varieties are selected on the base of different parameters (morphological, physiological, or biochemical) that are connected with Cd uptake. To improve the genotypes of Cd-tolerant wheat varieties, intra-specific crosses among superior individuals are usually done, followed by selection in next generations. Common breeding methods, such as mass selection, pure line, and recurrent selection can be effectively used in the development of low-Cd wheat varieties. (Zaid et al., 2018) Conventional selections are dependent upon environmental changes and thus require a widespread field trial, postponing the progress of variety development (Forster et al., 2014).

As a common breeding criterion, about 10 years of significant efforts are needed to breed a variety right from the pre-breeding stage up to commercial release (Collard & Mackill, 2008).

Conventional breeding has been succeeded and considerable breeding progresses benefit has been achieved in many valuable traits, such as yield, its quality, and stress tolerance. Practicing conventional methods for adaptation to abiotic stresses is challenging, as compared to breeding for other plant traits. For each of the abiotic stresses there are various mechanisms of resistance or tolerance, depending on the plant stress-adaptive nature (Slafer et al., 2014; Yue et al., 2018).

Despite these difficulties scientists used to solve this problem (development of low-Cd wheat varieties) by conventional breeding methods, i.e., introduction, selection, and hybridization. (Zaid et al., 2018) As a result, several low-Cd wheat cultivars were developed through conventional breeding approaches. For example, Yue (Yue et al., 2018) studied three wheat varieties under four different Cd

levels. Their results listed JD 8 as a Cd-tolerant sample, containing the lowest Cd content and had less toxicity compared to other ones. Naeem et al. (2016) tested 15 wheat cultivars under Cd concentrations of 15, 30, and 45 μM. The results revealed that Lasani-2008 and Iqbal-2000 exhibited the lowest Cd contents.

Moreover, a large number of conventional breeding studies were carried out to screen out Cd-safe wheat cultivars.

Conclusions. As a result of studying the collection samples of wheat (41 varieties) from different institution-originators, samples with valuable breeding characteristics were identified. Growth parameters (height) and leaf surface area were analyzed in the collection of winter wheat varieties. These traits were related to productivity parameters such as 1000 seed weight, grain weight per ear and yield.

Based on the analysis of the collection, wheat samples were isolated, which, along with high yields, were characterized by low Cd uptake. Depending on the values of cadmium content and parameters of plant productivity, group of varieties with minimum values of Cd (less than 1.2 mg / kg) was formed. It includes varieties of Okhtyrchanka Juvileina, Svitanok Myronivskyi, Melody Odes'ka, Kubok, Zorepad, Ovidiy, Shchedra Nyva, Oktava Odes'ka and Slaven. It is planned to use these samples for perspective breeding process.

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Дослідження колекції озимої пшениці для отримання вихідного матеріалу з низьким поглинанням кадмію

Озима пшениця є провідною культурою в Україні й світі та забезпечує харчові потреби людини. Провідні селекційні установи України вивчають колекції пшениці, що дає змогу виявити джерела та донори необхідних селекційних ознак та залучити їх до гібридизації. Для систематичної та успішної програми гібридизації має бути досягнуто глибоке розуміння генетичної архітектури врожайності рослин та інших важливих економічних характеристик. Одним із сучасних напрямків селекційної роботи є отримання вихідного матеріалу з низькою здатністю до накопичення важких металів, зокрема кадмію. Накопичення кадмію в грунті веде до його поглинання кореневої системою рослин та накочення в вегетативних та генеративних органах. Серед культур, які відзначаються високою здатністю до активного накопичення кадмію озима пшениця посідає одне з перших місць Нагальною необхідністю є мінімізація накопичення Cd у зерні пшениці. В багатьох країнах розробляються технічні рішення щодо зниження вмісту цього металу в насінні культури. Одним із можливих шляхів вирішення цієї проблеми є створення селекційних сортів, які характеризуються низькою здатністю накопичувати кадмій. Використовуються методи традиційної селекції: добір та гібридизація. Метою дослідження було встановлення селекційної цінності колекційних генотипів озимої пшениці різних за походженням, морфологічними та продуктивними параметрами, виділення та створення вихідного матеріалу для селекції. Польовий експеримент проводили на науково-дослідному полі Сумського НАУ. Вивчали 41 сорт пшениці озимої, оригінаторами яких є 7 основних селекційних центрів цієї культури в Україні. Було проаналізовано параметри росту (висота рослин) та площа листкової поверхні. Ці ознаки були пов'язані з такими параметрами продуктивності, як маса 1000 насінин, маса зерна на колос та врожайність.

За результатами виділено зразки пшениці, які, поряд з високими параметрами продуктивності, мали низьку здатність до поглинання Cd (менше 1,2 мг/кг). До цієї групи входять сорти Охтирчанка Ювілейна, Світанок Миронівський, Мелодія Одеська, Кубок, Зорепад, Овідій, Щедра Нива, Октава Одеська та Славен. Ці зразки планується використовувати для подальшої селекційної роботи .

***Ключові слова:** озима пшениця, колекція, цінні селекційні ознаки, низьке поглинання Cd, вихідний матеріал.*