

DIFFERENTIATION OF BREAD WINTER WHEAT BREEDING LINES BY FROST HARDINESS IN THE FOREST-STEPPE OF UKRAINE

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Topicality. Wheat is one of the most strategic and indispensable agricultural crops. High yields require the development of highly adaptive winter wheat varieties. Regional climatic fluctuations significantly affect plant growth and development, which makes it essential to consider plant resistance to abiotic stressors. Meteorological conditions during the autumn-winter period are crucial for the successful overwintering of winter crops. **Purpose.** To differentiate breeding lines of bread winter wheat by frost hardiness under conditions of Forest-Steppe and to identify the influence of air temperature during the hardening period on the development of this trait in plants. **Materials and methods.** The studies were carried out at the V. M. Remeslo Myronivka Institute of Wheat NAAS of Ukraine. A total of 17 bread winter wheat breeding lines from competitive trials were studied. The Myronivska 808 variety was used as a standard. After the plants were hardened in open field conditions, their frost hardiness was determined using the freezing method in KNT-1 low-temperature chambers at -18°C . The reliability of the data was verified using Fisher's criterion. **Results.** The data obtained over three years of research confirmed that the air temperature regime during the hardening period of bread winter wheat plants influenced the formation of their frost hardiness. Sharp fluctuations in air temperature, changes in their daily values from positive to negative during the day and at night led to a violation of hardening conditions, which resulted in a decrease in frost hardiness of plants. The favourable hardening conditions in 2021/22 and 2022/23 resulted in frost hardiness of 96 % and 89 %, respectively. Under unfavourable conditions in 2023/24, the survival rate of plants was recorded at 67 %. A correlation coefficient ($r = -0.99$) between the percentage of surviving plants after freezing and the average air temperature during the hardening period was determined. Over the three years of research, Lutescens 60873 line was identified by the level of frost hardiness, which was at the level or higher than the standard variety. **Conclusions.** Lutescens 60873 line is recommended as a valuable initial material for further breeding improvement of the crop. The obtained results are aimed at enhancing the understanding of plant responses to temperature fluctuations during the autumn-winter period, which will allow for an objective characterization of the adaptability level of promising winter wheat genotypes and enable forecasting of their performance under specific environmental conditions.

Key words: bread winter wheat, breeding lines, frost hardiness, air temperature, plant hardening

Introduction. Wheat is one of the strategic and essential agricultural crops [1]. In recent years, the climate has been characterised by rapid changes in weather conditions with significant fluctuations in precipitation and temperature [5]. Such changes significantly affect plant growth and development and require studying the response of wheat varieties to the negative impact of environmental factors [2]. At the present time, it is necessary to conduct selection to develop varieties that have a high level of re-

sistance to adverse environmental factors [3, 4]. According to the data, the hydrothermal regime significantly affects the yield of winter wheat throughout the entire growing season, however, meteorological conditions in the autumn-winter period are decisive for the excellent overwintering of winter crops [5, 6].

Plant winterkill is one of the main adverse factors in the natural environment that affects the overwintering of winter wheat plants [7]. Considered to be necessary for plants to acquire

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high winter hardness and frost resistance, two hardening stages must be completed. The first hardening stage occurs at daytime air temperatures ranging from 8 to 10 °C and night-time temperatures ranging from 0 to 4 °C. During this stage, sugars are actively accumulated as protective substances. The second hardening stage occurs at an average daily temperature of 0 to -5 °C. This stage can even happen under snow cover without sunlight [8]. The duration of the first stage of wheat hardening varies from 12 days to 12–14 weeks [9, 10]. It is noted that with a longer duration of the first stage of hardening (30–40 days), frost resistance decreases, and prolonging the winter period generally reduces the winter hardness of winter wheat plants [11, 12]. Scientists note that currently, breeding methods for winter wheat based on plant frost resistance and ways to prevent a decrease in their tolerance during thaws, as well as the rate and degree of plant condition recovery when frosts return, are still insufficiently developed. The issues of plant resistance to low sub-zero temperatures, identification and realisation of the genetic potential for frost resistance in plants remain relevant to this day [13, 14, 15]. Relevant task for modern scientific research remains improving and developing existing and new methodological approaches to assessing frost resistance in grain crop breeding [16, 17].

The research was aimed at differentiating soft winter wheat breeding lines according to frost resistance in the conditions of the Forest-Steppe of Ukraine and identifying the influence of air temperature during hardening on the formation of frost resistance in plants.

Materials and Methods. The research was conducted at the Biotechnology, Genetics and Physiology Department of the V. M. Remeslo Myronivka Institute of Wheat (MIP) in 2021–2024. The material for the research was 17 breeding lines of bread winter wheat selected by the Winter Wheat Breeding Laboratory in competitive trials. The Myronivska 808 variety was used as a standard. The frost resistance of plants was determined according to DSTU 4749:2007 [18] using the freezing method in KNT-1 low-temperature chambers, which involves the following procedure. Boxes with a size of 30×40 cm and a depth of 12–15 cm were filled to 3–4 cm below the upper edge with sifted soil. The soil surface was levelled and divi-

ded into rows with a distance of 3–4 cm between them. The experimental material was sown in boxes, 20–25 seeds in each row, and covered with 3 cm layer of soil. Three rows of the standard variety were also sown in each box. After sowing, the boxes were placed in an open area under natural conditions to allow the plants to complete two hardening stages. The plant care consisted of systematic watering. The breeding material was frozen in the first ten days of January, starting at a temperature corresponding to the ambient environment and reducing it by 2 °C every hour to the set value. For the assessment of frost resistance, exposure to freezing temperatures for 24 hours at -18 °C was used. After gradual thawing (over 2 days), the boxes with the winter wheat were placed in rooms with a temperature of 18 to 24 °C and the plants were prepared for regrowth – they were trimmed, and a leaf blade 0.5 cm long was left. A preliminary count of living and dead plants was carried out after 10–12 days, and the final count after 15–16 days.

To characterize the temperature regime during the plant hardening period, the average daily (6:00 am, 9:00 am, 12:00 pm, 3:00 pm) and average night-time (6:00 pm, 9:00 pm, 12:00 am, 03:00 am) air temperatures were determined for the period from 10 November to 15 December. The total period covered is 36 days, which is the expected duration of the two hardening stages.

The reliability of the data obtained was determined using Fisher's criterion. The regression equation was calculated and the correlation coefficient was determined using Microsoft Excel software. For the interpretation of Pearson's correlation coefficient (r), we used Chaddock's scale [19]: $0 < r < 0.09$ – no correlation, $0.10 < r < 0.29$ – weak correlation, $0.30 < r < 0.49$ – moderate correlation, $0.50 < r < 0.69$ – significant, $0.7 < r < 0.89$ – strong, $0.90 < r < 0.99$ – very strong, $r = 1.00$ – functional relationship.

Results and Discussion. Analysis of temperature conditions during the autumn-winter period of the years of research revealed climatic changes during the autumn vegetation of wheat, characterised by an increase in the average monthly air temperature and its sharp fluctuations (Fig. 1).

Over the years of research, the end of autumn vegetation of winter wheat was observed

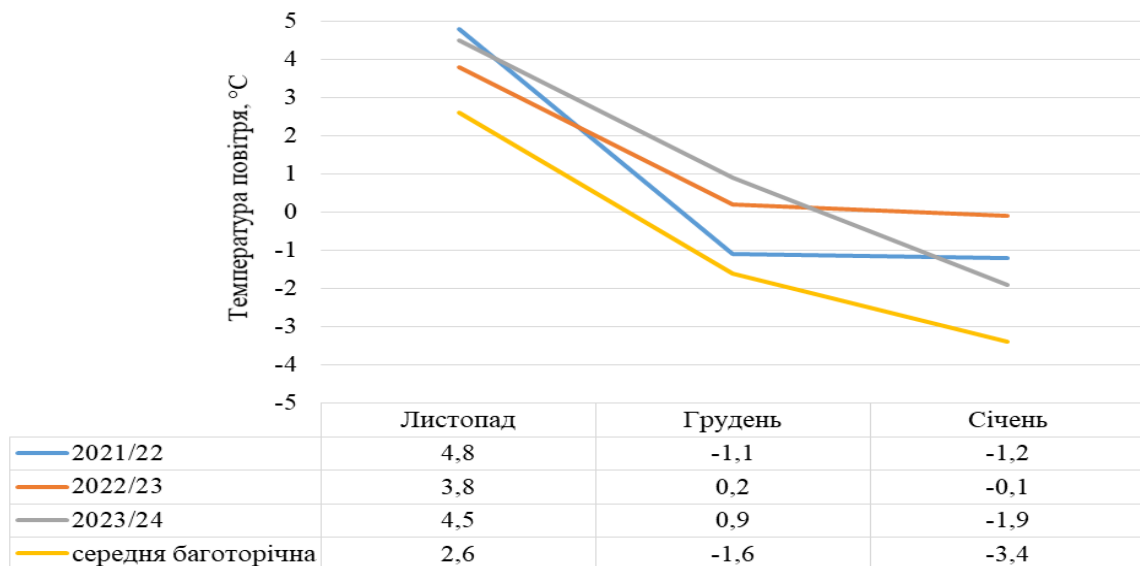


Fig. 1. Characteristics of the temperature regime in the autumn-winter period 2021/22–2023/24.

in November (2021 – 23 November, 2022 – 15 November, 2023 – 16 November). The average monthly air temperature this month ranged from 3.8 °C (2022) to 4.8 °C (2021). In 2021, the average daily temperature below 0 °C was observed from 16 to 18 November and ranged from -0.4 to -2.5 °C. In 2022, such a temperature curve with a value of -0.3 to -0.6 °C was observed on 18, 20 and 30 November. In 2023, after the cessation of vegetation (16 November), the temperature regime was characterised by sharp fluctuations in air temperature. A decrease in the average daily temperature was observed from 19 to 23 November (from -1.4 to -3.1 °C), from 26 to 28 November (-1.3 to -3.4 °C) and on 30 No-

vember (-2.2 °C). The average long-term air temperature in December was -1.6 °C, but during the years of research, slightly higher values were observed, which were -1.1 °C (2021/22), 0.6 °C (2022/23) and 0.9 °C (2023/24). This temperature regime indicates the probability of a prolongation of the first stage of plant hardening in 2023/24. The average monthly air temperature in January ranged from -0.1 °C to -1.9 °C, while the long-term average was -3.4 °C.

In accordance with the aforementioned theory of plant hardening, the average daily and night-time air temperatures were determined for the period from 10 November to 15 December (Fig. 2).

In 2021/22, this period was characterised

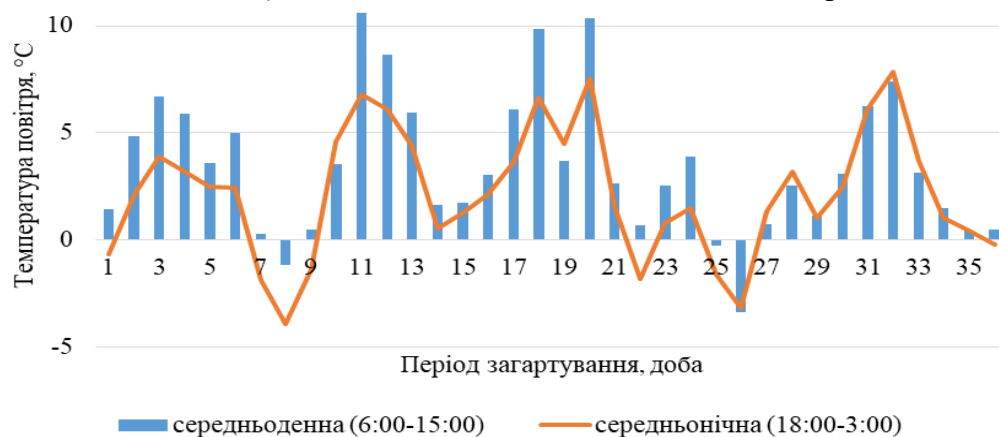


Fig. 2 Average daytime and night-time air temperature during the hardening period.

by relatively high air temperatures, which exceeding 10 °C on some days. The air temperature dropped below 0 °C twice, after which a gradual increase in temperature was observed both during the day and at night. The tempera-

ture regime during the hardening period in 2022/23 was variable, the air temperature gradually changed from low to high (Fig. 3).

On day 32, the air temperature increased to 9.0 °C during the day and to 8.3 °C at night, after

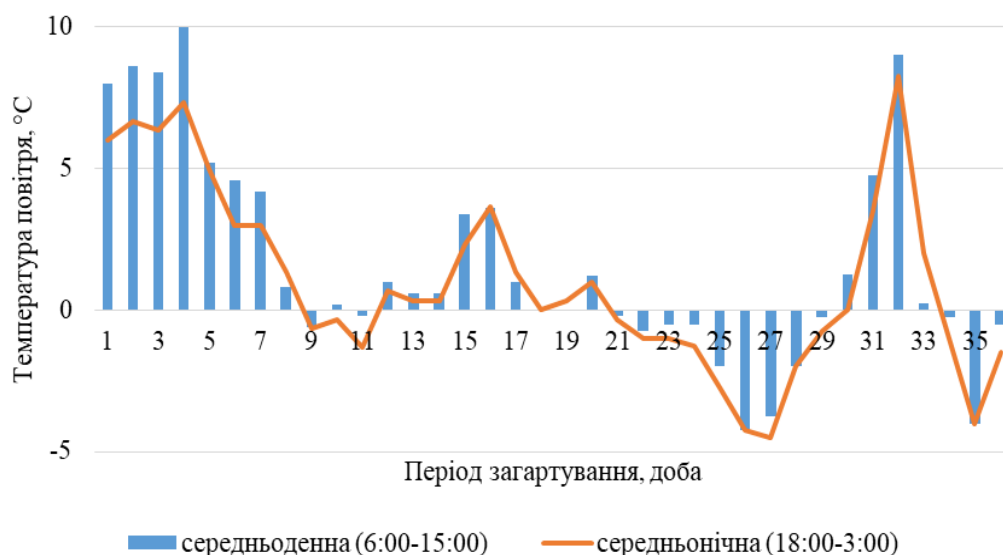


Fig. 3 Characteristics of temperature regime during the hardening period of bread winter wheat in 2022/23.

which it dropped to $-4.0\text{ }^{\circ}\text{C}$. In general, the conditions in 2021/22 and 2022/23 were satisfactory for the first and second stages of plant hardening, as the average daytime and night-time air tempera-

tures were identical, i.e. above or below zero. In 2023/24, there were fluctuations in daily air temperature (Fig. 4).

From the 10th to the 14th day (19–23 No-

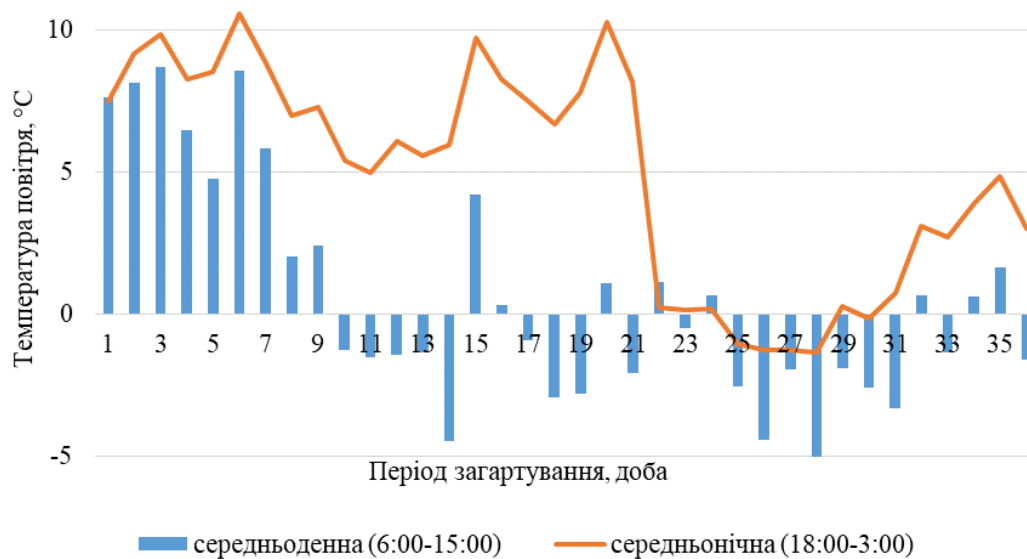


Fig. 4 Characteristics of temperature conditions during the hardening period of bread winter wheat in 2023/24.

vember) of the hardening period, the average daily air temperature ranged from -1.3 to $-4.5\text{ }^{\circ}\text{C}$, and the average night-time temperature ranged from -5.0 to $-6.0\text{ }^{\circ}\text{C}$. Temperature fluctuations were observed throughout the entire research period. For determination of frost resistance, the method of hardening plants under natural conditions was used. It was found that the highest level of frost resistance (96 %) of winter wheat lines was formed under the temperature conditions of 2021/22, and the lowest (67 %) in 2023/24. A number of lines were selected

whose frost resistance was reliably at the level of the standard variety, namely Erythrosperrum 60724, Lutescens 60181, Lutescens 60729, Lutescens 60874, and Lutescens 60766 (Table 1).

Lines were also identified in which the percentage of live plants after freezing was higher in one year and at the level of the standard variety in other years: Lutescens 60873 (81–100 %), Erythrosperrum 60899 (73–98 %), Lutescens 60734 (72–100 %).

The correlation coefficient between the percentage of living plants after freezing and the

Table 1. Frost resistance of bread winter wheat lines in competitive testing for freezing at -18 °C

Standard variety and breeding line name	Number (% ± s _p) of living plants		
	2021/22	2022/23	2023/24
Myronivska 808 – standard	95±2.6	86±4.6	78±5.4
ErythrospERMum 60724	99±1.2*	89±4.3*	84±4.7*
Lutescens 60873	97±2.1*	100±0.0**	81±5.5*
Lutescens 60702	100±0.0**	77±5.6*	81±5.0*
Lutescens 60181	97±2.0*	82±5.0*	76±5.5*
Lutescens 60355	100±0.0**	90±4.3*	73±5.6*
ErythrospERMum 60899	94±2.7*	98±1.9**	73±5.6*
Lutescens 60734	100±0.0**	79±5.4*	72±5.6*
Lutescens 60729	99±1.1*	90±4.0*	68±6.0*
Lutescens 60874	99±1.1*	84±4.9*	68±5.8*
Lutescens 60896	82±4.4	91±3.9*	66±7.2*
Lutescens 60766	95±2.5*	93±3.4*	64±6.9*
Lutescens 60510	97±2.0*	95±3.0*	61±6.2
Lutescens 60430	97±2.1*	97±2.2**	59±6.2
ErythrospERMum 60793	99±1.2*	78±5.4*	58±6.2
Lutescens 60412	99±1.2*	75±5.7*	56±6.4
Lutescens 60879	78±4.8	97±2.2**	55±7.3
Lutescens 60680	97±2.0*	95±2.9*	41±6.2
Average	96	89	67

Notes. * Not significantly different from the standard (according to Fisher's criterion), **significantly higher than the standard.

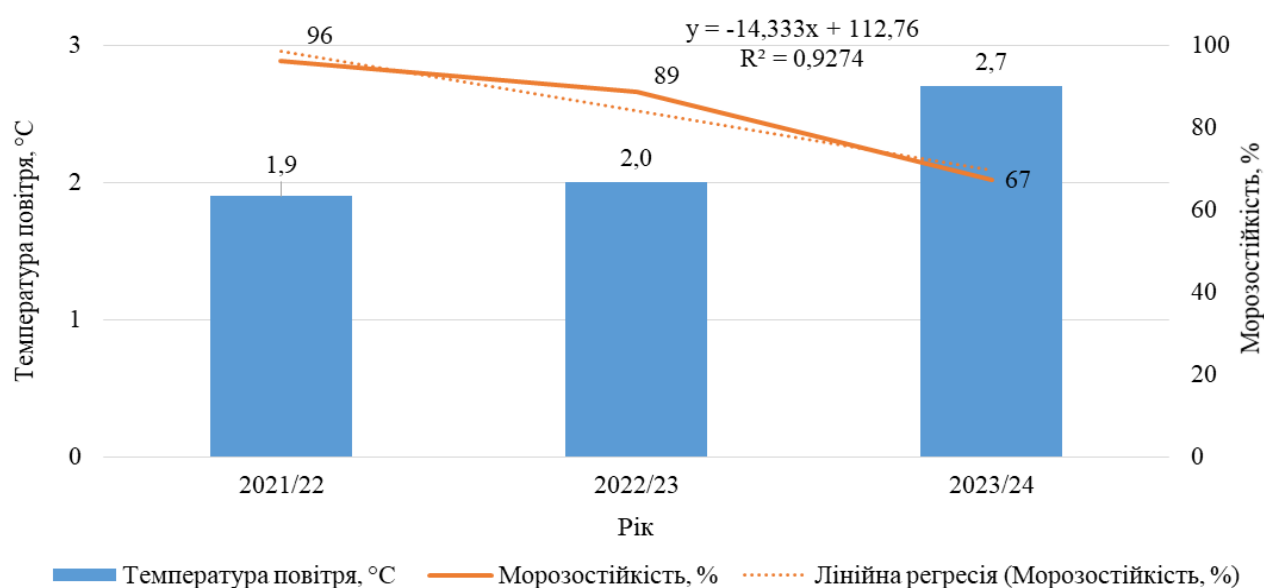


Fig. 5 Frost resistance of winter wheat plants at -18 °C depending on temperature conditions in the autumn-winter period (November, December) 2021/22–2023/24.

average air temperature during the hardening stages ($r = -0.99$) was determined, indicating a very strong inverse relationship between these indicators. The correlation coefficient confirms the influence of the temperature regime during the hardening period on the formation of plant frost resistance. Our previous studies have shown that plant hardening was significantly

more effective with a gradual decrease in air temperature than with sharp fluctuations [20]. The regression equation confirms that as the air temperature rises during the hardening period, plant frost resistance decreases (Fig. 5).

Conclusions. The data obtained during three years of research demonstrated the impact of temperature conditions during the hardening period

of bread winter wheat plants on the formation of their frost resistance. Sharp fluctuations in air temperature, with daily values changing from above zero to below zero during the day and night, led to a disruption in hardening conditions, resulting in reduced frost resistance of plants. Under favourable hardening conditions in 2021/22 and 2022/23, frost resistance was 96 % and 89 %, respectively. Under unfavourable conditions in 2023/24, the number of living plants was recorded at 67 %. The correlation coefficient between the percentage of living plants after freezing and the average air temperature during the hardening phase was deter-

mined ($r = -0.99$). We identified the Lutescens 60873 line with a frost resistance level equal to or higher than the standard variety over three years of research. This line can be a valuable starting material for further breeding improvement of the crop. The results obtained are aimed at developing an understanding of plant responses to temperature changes in the autumn-winter period, which will make it possible to objectively characterise the level of adaptability of promising winter wheat genotypes and predict their survival in the corresponding environmental conditions.

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Актуальність. Пшениця є однією з стратегічних та незамінних сільськогосподарських культур. Для отримання високих врожаїв необхідно створювати високоадаптивні сорти пшениці озимої. Регіональні кліматичні флуктуації істотно впливають на ріст і розвиток рослин, тому важливим є врахування їх стійкості до абіотичних стресорів. Метеорологічні умови в осінньо-зимовий період є визначальними для відмінної перезимівлі озимих культур. **Мета.** Провести диференціацію селекційних ліній пшениці м'якої озимої за морозостійкістю в умовах Лісостепу України та виявити вплив температурного режиму повітря під час загартування на формування рівня цієї ознаки у рослин. **Матеріали і методи.** Дослідження проводили у 2021–2024 рр. у Миронівському інституті пшениці імені В. М. Ремесла НААН України. Досліджували 17 селекційних ліній пшениці м'якої озимої конкурсного випробування. За еталон використовували сорт Миронівська 808. Після загартування рослин на відкритому майданчику визначали їх морозостійкість методом проморожування в камерах КНТ-1 за температури -18 °С. Достовірність отриманих даних перевіряли за критерієм Фішера. **Результати.** Отримані дані впродовж трьох років досліджень засвідчили про вплив температурного режиму у період загартування рослин пшениці м'якої озимої на формування їх морозостійкості. Різкі коливання температури повітря, зміна їх добових значень від плюсових до мінусових удень та вночі призводили до порушення умов загартування, у результаті чого знижувалася морозостійкість рослин. За сприятли-

вих умов загартування у 2021/22 та 2022/23 рр. морозостійкість становила 96 % та 89 % відповідно. За незадовільних умов 2023/24 р. кількість живих рослин відмічено на рівні 67 %. Визначено коефіцієнт кореляції між відсотком живих рослин після проморожування та середньою температурою повітря у період проходження фаз загартування ($r=-0,99$). Виділено лінію Лютесценс 60873, морозостійкість якої за три роки досліджень відмічено на рівні або вище сорту-еталону. **Висновки.** Лінія Лютесценс 60873 може слугувати цінним вихідним матеріалом для по-дальшого селекційного вдосконалення культури. Отримані результати орієнтовані на розвиток розуміння реакцій рослин на зміну температур осінньо-зимового періоду, що дасть можливість об'єктивно характеризувати рівень адаптивності перспективних генотипів пшениці озимої та прогнозувати їхню поведінку у відповідних екологічних умовах.

Ключові слова: пшениця м'яка озима, селекційні лінії, морозостійкість, температура повітря, загартування рослин