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Influence of weather conditions on winter wheat (*Triticum aestivum* L.) overwintering

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Abstract. The aim of the study was to determine the effect of hydrothermal conditions, duration of winter and varietal characteristics on the sugar content in tillering nodes and, accordingly, on wintering of м plants in the Right-Bank Forest-Steppe of Ukraine. The direct dependence of the amount of sugars in the tillering nodes of winter wheat (*Triticum aestivum* L.) on the sum of effective temperatures and the duration of autumn vegetation was established. It was found that under the most favorable conditions prevailing in the autumn growing season of 2019, with the sum of effective temperatures of 984.6 °C and the duration of the autumn growing season of 76 days, the amount of accumulated sugars was 4.7% higher compared to 2016, and was 30.6%. It was found that over the years of research, the sugar content in the tillering nodes of winter wheat (*Triticum aestivum* L.) was higher in mid-season varieties, but there was no significant difference in varieties within the same maturity group, which confirms the high adaptability of the studied varieties to the soil and climatic conditions of the Right-Bank Forest-Steppe of Ukraine. Favorable climatic conditions in autumn and winter over the years of observation ensured good growth and development of plants in the pre-winter period and contributed to the accumulation of optimal amounts of sugars in tillering nodes, which ensured high winter survival of plants of all winter wheat (*Triticum aestivum* L.) varieties. The lowest percentage of overwintering was observed in Gorodnitsa variety at 98.8%, and the highest in Astarta variety with an average of 99.8% over the years of research.

Key words: sum of effective temperatures, sugars, winter hardiness, tillering node, plant safety, winter duration.

INTRODUCTION

Ukraine holds a leading position in the global grain market with an export potential of 40 million tonnes out of 752 million tonnes of global grain production (Morhun & Rybalka, 2017; Erenstein et al., 2022). As one of the world's leading grain exporters, the country will play a significant role in providing food and grain raw materials to the ever-growing Earth population, estimated to reach almost 10 billion in 2050 (Morhun & Rybalka, 2017; Demestichas et al., 2020). Winter wheat (*Triticum aestivum* L.) has been

and remains the leading crop in Ukraine, and there is no alternative to it (Matviychuk et al., 2023).

Studies have shown that the growth, development and productivity of winter wheat (*Triticum aestivum* L.) are most significantly affected by weather conditions, varietal characteristics and cultivation techniques (Linina & Ruza, 2018; Mostipan et al., 2021). In particular, climatic factors regulate the physiological and biochemical processes that occur in plants and significantly affect the quality of grain and yield of winter wheat (*Triticum aestivum* L.) (Kulyk et al., 2020). The autumn period of growth and development of *Triticum aestivum* is critical for the formation of crop productivity, so the consequences of mistakes made in the fall cannot be eliminated later by optimizing agricultural technology (Kalenska & Gordina, 2022). Therefore, all agrotechnological measures should be aimed at creating favorable conditions for the growth and development of crops (Pysarenko et al., 2022; Mashchenko & Sokolovska, 2023). Ukraine is located in different climatic zones and characterized by a large diversity of ecosystems. Climate change at the global level can manifest itself differently at the regional level, as climate indirectly affects other interrelated ecosystem factors (Boychenko et al., 2016). Therefore, it is important to study the impact of weather conditions on winter wheat (*Triticum aestivum* L.) overwintering, which determines its productivity.

Analysis of recent research and publications. Winter wheat (*Triticum aestivum* L.) overwintering conditions are decisive in the growing season. The crop failure is not only a shortage of millions of tons of grain, but also the seeds sown in vain, as well as additional costs for processing the soil and reseeding the fields. At sub-zero temperatures critical for culture (especially when they are established suddenly or immediately after thawing), freezing occurs, which leads to the crop failure. Free water molecules between the cells turn into ice crystals, which is the main reason for damage to seed sprouts. After thawing, such plants lose turgor, quickly turn yellow and dry (Hasanfard et al., 2021). Strong dehydration of cell protoplasm due to freezing of free water in intercellular spaces with the formation of crystals or a continuous ice shell at a sudden drop in temperature leads to dehydration of cells and coagulation of colloidal solutions in cells of winter crops and their failure (Avramenko et al., 2016a).

A sharp drop in temperature during the transition to the winter period, stress factors weaken winter resistance, which leads to their partial or complete failure. The dominant condition is also the property of the varieties to accumulate amount of sugars in the tillering nodes. Accumulating in cells, sugars increase the concentration of cell sap and reduce the water potential. The higher the concentration of cell sap, the lower its freezing point, so the accumulation of sugars stabilizes cell structures, in particular chloroplasts, allowing them to function at temperatures close to 0 °C. Of particular importance is the protective effect of sugar on proteins concentrated in the surface membranes of the cell (Bliznyuk et al., 2019).

One of the factors that contribute to the formation of plant winter hardiness is the accumulation of reserve nutrients in cells during the fall. This process can occur with intensive photosynthesis and slower growth processes (Turebayeva et al., 2022). Plant resistance to frost is determined by the amount of sugars in the tillering nodes, which ensure the structural and functional stability of cells when they lose moisture. Sugars are the main protective substances in plant development (Liu et al., 2013). The accumulation

of sugars in the tillering nodes and an increase in the concentration of soluble sugars occurs during plant hardening, which takes place in two stages: Phase I - at daytime temperatures of about 8–10 °C, at night - from 0 to 4 °C, Phase II - at an average temperature of 0 to 5 °C (Avramenko et al., 2016b). The aim of the research was to determine the effect of hydrothermal conditions, winter duration and varietal characteristics on the sugar content in tillering nodes and, accordingly, on the wintering of Triticum aestivum.

MATERIALS AND METHODS

Field and laboratory studies were conducted at the Institute of Plant Physiology and Genetics of the National Academy of Sciences and its experimental farm located in the Right-Bank Forest-Steppe of Ukraine during 2016–2020.

Climatic conditions

The climate in the research area is temperate continental. The average annual daily air temperature is 7 °C with deviations in some years from 5 to 8 °C. The minimum temperature in winter months is -26 °C. The sum of positive temperatures above 10 °C ranges from 2,650–2,660 °C. The average annual precipitation in the region is 538 mm; in some years it ranges from 350 to 850 mm. Precipitation is distributed rather unevenly throughout the year: most of it falls in the warm season, and the least in the winter. The average long-term duration of the frost-free period over the past 15 years has been 160–170 days and has tended to increase.

Seasonal changes usually occurred gradually. According to the average long-term data, sring began at the end of the second decade of March and was characterized by an intense temperature increase, which caused the soil to thaw quickly to the depth of plowing, with a steady transition to subzero temperatures through 0 °C occurring in late November. This time is considered the beginning of winter.

Plant material

The study was conducted with Winter wheat (*Triticum aestivum*) varieties of two maturity groups - medium-early maturing (Podolyanka, Pochaivka, Boria, Novosmuglianka, Slavna and Natalka) and early maturing (Horodnytsia, Astarta, Bohdana, Malynivka, Fovarytka), selected by the Institute of Plant Physiology and Genetics of the National Academy of Sciences.

Statistical analysis

Overwintering was calculated as the ratio of the number of plants that survived until spring to the total number of plants obtained in autumn.

The research methods in the study are: statistical methods; correlation and regression analysis; analysis and synthesis. The sugar content was determined by photometry using picric acid. A colourimeter was used to determine the sugar content. Statistical processing of the experimental data was carried out by the methods of analysis of variance according to the Fisher method (Fisher, 2006) using Statistica software (Ermantraut et al., 2007).

RESULTS AND DISCUSSION

It was found that the accumulation of sugars in the tillering nodes of winter wheat (*Triticum aestivum* L.) was influenced by the temperature regime of the autumn period (the sum of effective temperatures), the duration of the growing season in autumn, and the biological characteristics of varieties. It is known that the sum of effective temperatures is used to assess the impact of weather conditions, which is the sum of average daily temperatures reduced by the biological minimum (Polovyi et al., 2012).

It is known that photosynthesis of winter wheat occurs at air temperatures of -6 to -8 °C, and the decrease in the temperature minimum of this process is due to the frost resistance of plants (Polovyi et al., 2014). Research has shown that in order to develop good winter hardiness in winter wheat, plants need to grow for at least 40–60 days before the end of the autumn growing season (Bazalii et al., 2016). Accordingly, the accumulation of a sufficient amount of sugars in the tillering node is possible when the crops reach the sum of effective temperatures of 300–350 °C during the period from sowing to a stable transition through 5 °C (Hordyna, 2021).

On average, over five years, the sum of effective temperatures, which exceeded the long-term average by 203.4 °C and the duration of the autumn growing season, which was 68 days, provided the accumulation of 29.0% of sugars in the tillering nodes (Table 1).

Table 1. Influence of autumn temperature regime during the growing season of winter wheat (*Triticum aestivum* L.) on sugar content in tillering nodes (2016–2020)

Year	Sum of effective temperatures, °C for the autumn period	Average long-term data	Duration of autumn vegetation of plants, days	Sugar content, %
2016	749.0	709.6	56	26.2
2017	856.0		65	27.0
2018	915.9		70	29.3
2019	984.6		76	30.6
2020	1059.6		73	29.8
Average	913.0		68	29.0

Gordina's research has shown that with a change in the sum of effective temperatures from 242.3 to 378.5 °C and the duration of the autumn growing season from 48 to 56 days, plants significantly increase their field germination, plant density, sugar content and winter hardiness (Hordyna, 2021).

Our research showed similar results. Thus, in 2016, with a lower amount of positive temperatures - 749 °C and the duration of the autumn vegetation of 56 days, the average amount of sugars in the tillering nodes of plants was the lowest - 26.2%. In 2017, with a higher sum of effective temperatures in autumn by 107.0 °C and a longer growing season, the amount of sugars increased by 0.8%.

The most favorable was the autumn growing season, when the sum of effective temperatures was 984.6 °C, and the duration of the autumn growing season was the longest - 76 days, which provided the largest amount of sugar accumulation - 30.6%. The year 2020 was the closest to such conditions in the fall growing season. With the sum of effective temperatures exceeding the long-term average by 350 °C, but the vegetation period was shorter by 3 days, the amount of sugars in the tillering nodes was only 0.8% lower than in 2019.

Vorona and others (Vorona et al., 2013) have found that there is a close direct correlation between plant sugar content and the sum of effective temperatures ($r = 0.69$). Under conditions that promote intensive plant photosynthesis, sugars necessary for effective overwintering accumulate in cells.

Our correlation and regression analysis also revealed a strong linear correlation between the sugar content in tillering nodes and the sum of effective temperatures in the autumn period with a determination coefficient of $R^2 = 0.8522$ and a correlation coefficient of $r = 0.923$ (Fig. 1).

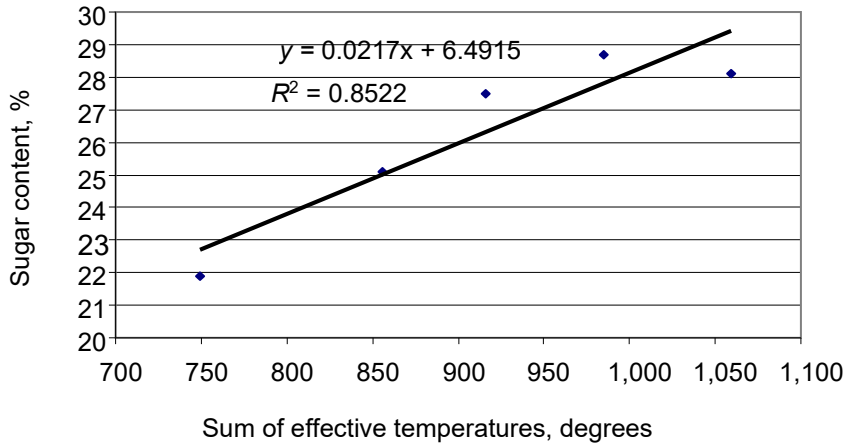

Figure 1. Dependence of sugar content in tillering nodes on the sum of effective temperatures in the autumn period (average for 2016–2020).

The regression equation describing this dependence was constructed: $y = 0.0217x + 6.4915$, an increase in the sum of effective temperatures promotes greater accumulation of sugars in the tillering nodes of winter wheat.

Depending on the varietal characteristics, the sugar content in the tillering nodes of winter wheat (*Triticum aestivum* L.) varied over the years of research, it was higher in mid-season varieties, but there was no significant difference in varieties within the same maturity group (Table 2). This confirms the high adaptability of the varieties studied by the Institute of Plant Physiology and Genetics to the soil and climatic conditions of the Right-Bank Forest-Steppe of Ukraine and indicates their good adaptive properties.

High adaptive properties of varieties to changes in external factors ensure optimal growth and development of plants and characterize their winter hardiness. That is why it is necessary to take them into account when introducing varieties into production, as abiotic factors have a significant impact on the productivity of varieties.

Winter periods also had their own peculiarities in terms of temperature and precipitation. The highest precipitation during the dormant period (from the III decade of November to the II decade of April) was in 2018–2019 - 307.1 mm, with a long-term average of 253.0 mm, and the rest of the years were low snow (Table 3). During this period, 46 days were with precipitation, including 36 days in winter. The plant survival rate by spring was 99.5% on average across varieties.

Table 2. Sugar content in winter wheat (*Triticum aestivum* L.) depending on biological characteristics and meteorological indicators (average for 2016–2020)

Variety	Sugar content, % by year					Average
	2016	2017	2018	2019	2020	
Medium-early ripening						
Podolyanka	25.9	27.1	29	30.5	30.1	28.5
Pochayivka	25.6	26.8	28.6	30.4	29.9	28.3
Boria	25.7	26.9	29.5	30.6	29.6	28.5
Novosmuglyanka	-	-	29.2	30.4	29.7	29.8
Slava	25.9	26.7	28.9	30.2	29.6	28.3
Natalka	26.3	26.8	28.9	30.6	29.6	28.4
Average by variety	25.9	26.8	29.0	30.4	29.7	28.6
Medium-ripening						
Gorodnitsa		-	29.7	30.8	29.3	29.9
Astarta	-	-	29.6	30.6	29.4	29.9
Bogdana	26.8	26.9	29.5	31.0	30.5	28.9
Malynivka	26.5	27.1	29.4	30.8	30.3	28.8
Favoritka	26.1	27.3	29.6	30.9	30.2	28.8
Average by variety	26.5	27.1	29.6	30.8	29.9	29.3
LSD_{05}	0.6	0.4	0.6	0.5	0.3	0.4

According to the temperature regime of 2018–2019, the dormant period of plants from the end of vegetation to its resumption was minus - 61.5 °C - the coldest, higher than the long-term average by 3.5 °C, and the average daily temperature of the winter period was -2.0 °C, with a long-term average of -2.9 °C. Dormant periods in other years differed significantly in terms of both temperature and moisture supply. Thus, in 2016–2017 and 2020–2021, the sum of temperatures was significantly higher than the long-term average, while in 2017–2018 and 2019–2020 it was much lower. The duration of the winter period, when the air temperature crosses 0 °C, ranged from 29 days in 2020–2021 to 74 days in 2017–2018. Such weather conditions in the Right-Bank Forest-Steppe confirm climate change - global warming, which carries certain risks for the safety of winter seed crops, not even from freezing, but from bulging and falling out of plants.

Table 3. Wintering of winter wheat (*Triticum aestivum* L.) depending on hydrothermal factors of the growing season (average for 2016–2021)

Year	Hydrothermal factors during the dormant period of plants (from the III decade of November to the II decade of April)				Duration of the winter period with temperatures below 0 °C, days	Overwintering of plants, %
	Σ t °C	average perennial	precipitation, mm	average perennial		
2016–2017	203.1	-58.0	219.5	253.0	46	99.1
2017–2018	25.7		158.2		74	99.3
2018–2019	-61.5		307.1		71	99.5
2019–2020	28.1		193.8		69	99.8
2020–2021	457.6		123.1		29	99.7
Average	200.6		195.6		61	99.5

Warm autumn and winter periods during the years of research contributed to good growth and development of plants before winter and accumulation of sufficient sugars in tillering nodes, which ensured high overwintering of plants of all studied winter wheat (*Triticum aestivum* L.) varieties, which averaged 99.5% over the years, and plant preservation by varieties was in the range of 98.8–99.8% by spring (Fig. 2).

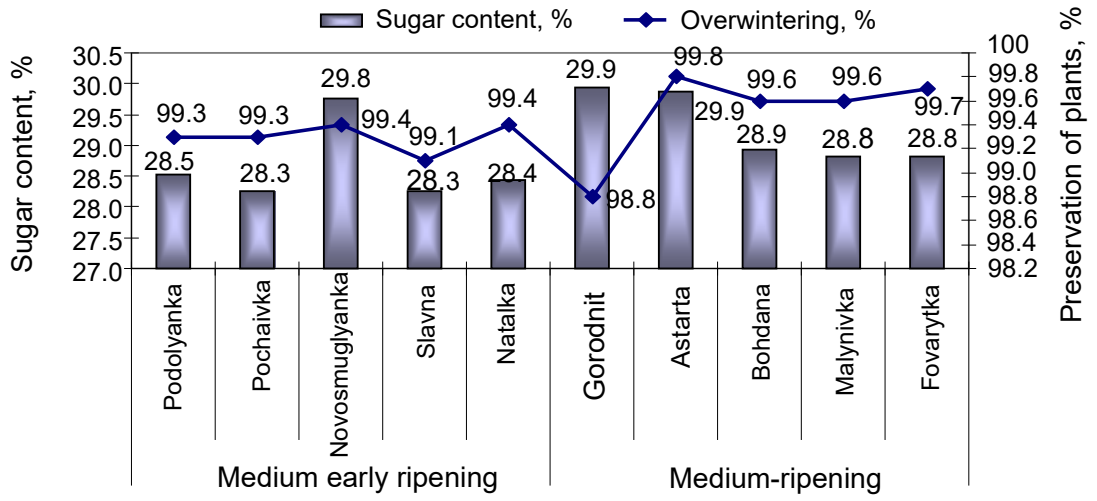

Figure 2. Wintering of plants and sugar content in tillering nodes of winter wheat (*Triticum aestivum* L.) varieties (average for 2016–2021).

A significant increase in the percentage of overwintering of plants depending on varietal characteristics was not found, which indicates high adaptive properties of varieties selected by the Institute of Plant Physiology and Genetics to adverse environmental conditions of the Right-Bank Forest-Steppe of Ukraine.

CONCLUSION

It was found that the sugar content in tillering nodes of winter wheat (*Triticum aestivum* L.) was influenced by the temperature regime of the autumn period (sum of effective temperatures), the duration of the autumn growing season and biological characteristics of varieties. On average, over five years, the sum of effective temperatures exceeded the long-term average by 203.4 °C and the duration of the autumn growing season of 68 days provided for the accumulation of 29.0% of sugars in the tillering nodes.

The most favorable was the autumn growing season, when the sum of effective temperatures was 984.6 °C, and the duration of the autumn growing season was the longest - 76 days, which provided the largest amount of sugar accumulation - 30.6%.

A strong linear correlation was found between the sugar content in tillering nodes and the sum of effective temperatures in the autumn period, with a correlation coefficient of 0.923.

Depending on the varietal characteristics, the sugar content in the tillering nodes of winter wheat (*Triticum aestivum* L.) varied over the years of research, it was higher in mid-season varieties than in early-season varieties, but there was no significant difference in varieties within the same maturity group.

Warm autumn and winter periods over the years of research contributed to good growth and development of plants before winter and accumulation of sufficient sugars in tillering nodes, which ensured high overwintering of plants of all winter wheat (*Triticum aestivum* L.) varieties, which averaged 99.5% over the years.

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