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Influence of varietal characteristics of winter wheat and weather conditions on lodging resistance and productivity

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Abstract. Growing technologies and variety selection are crucial for increasing yields and improving the quality of winter wheat grain. The area under winter wheat is the largest in Ukraine, which is associated with the production of high-quality grain. The aim of the study was to determine the influence of weather conditions and variety characteristics on winter wheat plant height, internode length, lodging resistance, productivity factor and yield during the years under study. In the course of the study, the following generally accepted methods were used: systematic approach, system analysis approach, analytical synthesis approach, field approach and statistical approach. The article presents data on the results of research with 20 varieties of soft winter wheat in the conditions of the Training and Practical Centre of Mykolaiv National Agrarian University from 2017 to 2023. Agricultural technology for growing winter wheat varieties is widespread in the steppes of southern Ukraine. The influence of weather conditions and varietal characteristics on lodging resistance and productivity of winter wheat was investigated.

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The results showed that the optimum plant height of winter wheat varieties ranged from 82.1 to 84.5 cm, and the highest yield was 6.32 t/ha in Staleva and 6.68 t/ha in Duma Odeska. A significant effect of varietal traits on stem length, second and last internode, number of stems formed per 1 m^2, grain weight in the ear and lodging resistance of winter bread wheat was established. Plants of the tested winter soft wheat varieties Staleva, Dyvo, Katarina, Felix, Ozerna, PONTICUS, Faust, Glaucus have a very high (9.0 points) resistance to lodging regardless of the weather conditions of the year. Ukrainian varieties Duma Odeska (6.68 t/ha) and Staleva (6.32 t/ha) achieved higher productivity. The obtained scientific results of the research contribute to the widespread use of the studied winter wheat varieties of this reasonably climatic zone and contribute to further improvement of grain production

Keywords: plant height; internode length; spike length; number of productive stems; weight of 1000 grains; soft winter wheat; amount of precipitation

INTRODUCTION

Under current conditions, an important factor in stabilizing and increasing high grain yields is the introduction of high-yielding, competitive new varieties with significant agro-ecological plasticity and increased adaptability to adverse and extreme environmental conditions, the most important of which is lodging resistance. In the south of Ukraine, where wheat crops often suffer from drought, plant height is almost always lower than in the north, so lodging is not common. However, in years with favourable moisture conditions and under irrigation, plants often lodge, resulting in significant yield losses.

Wheat is the main crop in many countries of the world, and in the steppe zone it is the main food crop, so the system of agronomic practices should focus on creating optimal conditions for high yields of this crop (Domaratskiy *et al.,* 2019). As the world's population grows, military operations lead to a decrease in the area of cultivated land and overall crop production, the problem of finding innovative ways to increase crop yields, thereby increasing global food supplies, arises. Wheat yields vary from year to year, depending on factors such as water availability during the growing season, the variety and agricultural practices used to grow the crop, and especially the nutrients applied (Panfilova, 2021).

The authors K. Mottaleb *et al.* (2022) and R. Ihle *et al.* (2022) pointed out that in poor countries, where people often suffer from hunger, wheat provides 14% of daily dietary energy and protein intake per person. Due to the hostilities in Ukraine, which is one of the world's major wheat producers and exporters, food prices have risen significantly, with serious implications for food security. According to the UN online database, in 2020, 864 million people – 8.9% of the world's population – suffered from hunger, while at least 63 countries imported wheat from Ukraine (The state of food security and nutrition…, 2020).

According to T. Rife *et al.* (2019), one of the ways to overcome the crisis in the global grain sector is to increase gross grain harvests by increasing yields. Studies conducted by O. Berdnikova and E. Kucherak (2021) found that variety selection is a key factor in obtaining technical indicators of high yield and grain quality. The development of new winter wheat varieties is one of the ways to increase the profitability of winter wheat cultivation, but the average yield of winter wheat in Ukraine is 2.5 times lower than in Western Europe. There are several reasons for this, one of which is the use of outdated varieties that do not meet the requirements of modern high-intensity farming.

The research of M. Korkhova *et al.* (2022) found that the determining criteria for selecting modern winter wheat varieties are the degree of durability and response to growing conditions. Each variety has certain morph-agrobiological traits and characteristics so that it can develop its genetic potential if a favourable environment is created for it. A. Muszynska *et al.* (2021) found that lower internode bending (stem bending) is common in wheat, barley, and oats due to a marked difference in weight and strength between the upper and lower internodes. Plant height; stem length, diameter, and weight; ear weight; and stem wall thickness of soft winter wheat are known to be most strongly related to lodging resistance.

The study conducted by T. Shah *et al.* (2019) found that lodging resistance is completely dependent on internode length, plant height and stem bending strength. Reducing plant height develops tolerance to lodging due to a relatively low centre of gravity and a decrease in the aboveground load of the plant on the lower part of the stem in rice. A negative relationship was found between basal internode length and lodging index, indicating that longer internodes at the base may lead to a higher lodging index in winter wheat plants.

Studies conducted by F.J. Piñera-Chavez *et al.* (2020) found that in plant breeding, checking lodging resistance is very difficult, as this quantitative trait is controlled by different genes, and its expression is significantly affected by environmental factors. M. Bondarenko & M. Nazarenko (2022) argue that high-yielding genotypes increase yields by producing more ears, are more resistant to lodging due to lower plant height and grain weight per ear, respectively, and use fewer nutrients for stem formation.

As of 11.04.2023, the State Register of Plant Varieties (2022) includes more than 600 varieties of soft winter wheat, but their economic and biological

characteristics, including lodging resistance, have not been sufficiently studied. During state variety testing, plants cannot always get into favourable weather conditions for stem growth, which can lead to lodging. Yields of winter wheat varieties are influenced by climatic conditions of crop cultivation and agricultural practices.

The analysis of scientific sources showed that the chosen topic has been studied insufficiently. That is why the aim of the work was to determine the influence of weather conditions and varietal characteristics during the study period on lodging resistance and productivity elements of winter wheat plants.

MATERIALS AND METHODS

The field trials were conducted over six years (2017-2023) at the Educational and Research Centre of Mykolaiv National Agrarian University, located in the South of Ukraine. The experimental scheme included 20 varieties of soft winter wheat of Ukrainian and foreign selection: Ozerna, Staleva, Kvitka poliv, Legend of Bila Tserkva, Mudrist Odeska, Maria, Duma Odeska, Dyvo, Koshova, Zdobna, Myronivsky Institute of Wheat (MIW) Assol, and MIW Valencia, Pamyati Hirka, Kraevid, Katarina, Centurion, Felix, PONTICUS, Faustus, Glaucus, which are short-stemmed (50%), semi-dwarf (35%) and medium-sized (15%) (Table 1).

Table 1. *Varieties of soft winter wheat by height (stem and ear)*

No	Medium-sized	Short-stemmed	Half dwarfs
1	Kvitka Poliv	Ozerna	MIW Valencia
2	The legend of Bila Tserkva	Steel	Katarina
3	MIW Assol	Mudrist Odeska	Centurion
4		Duma Odeska	Felix
5		Koshova	PONTICUS
6		Maria	Faustus
7		Zdobna	Glaucus
8		Dyvo	
9		Pamyati Hirka	
10		Kraevid	

Source: *developed by the authors*

Plants of all varieties tested had weakly filled straw. The area of the sowing plot was 70 m^2 and the accounting plot was 35 m^2. The experiment was designed by the method of randomization. Agricultural practices included sowing winter wheat in the first decade of October, using a seeding rate of 4.5 million seeds/ha. The soil of the experimental plot is a typical southern black soil, heavy humus with a slightly saline residue in the loess, humus content (0-30 cm) – 3.1-3.3%, average soil solution in the calculation (pH -6.8-7.2). On average, the topsoil contains 15-25 mobile nitrates, 41-46 mobile phosphorus and 389-425 mg/kg of exchangeable potassium.

The height of winter wheat plants was measured in the period before harvesting on 100 permanently allocated plants using a measuring ruler, which was evenly placed on the calculated area of each plot. The stem is measured from the soil surface to the top of the plant. The final indicator is the average height of the plants in the plot. The resistance to lodging of winter wheat plants was determined on a five-point scale: 5 points – no lodging, 4 points – weak lodging, 3 points – moderate lodging, 2 points – significant lodging, which complicates harvesting, 1 point — significant lodging occurs long before harvesting and the crop is not suitable for combining. Observations were made every 5-10 days from the onset of this phenomenon until harvest.

The weight of 1000 grains was determined according to DSTU ISO 520:2015 (2016). The average number of grains per ear was determined by the ratio of the total number of grains after threshing 25 ears to the sum of the average sample, and the weight of grain per 1 ear was determined by the weight of grain per sheaf to the number of productive stems in the sheaf sample. Harvesting was carried out continuously from the entire accounting area. Soft winter wheat was harvested with a SAMPO-500 combine harvester (Finland). After threshing in each plot, the combine was stopped, and the grain was weighed and brought to the standard moisture content (14%) and purity (100%). The weather conditions during the years of research differed significantly. Thus, the 2017/2018, 2021/2022 and 2022/2023 agricultural years were medium-wet, with 338.5, 331.6 and 343.4 mm of precipitation during the growing season, respectively, while in 2019/2020 – 161.2 mm; 2018/2019 – 547.6 mm and 2020/2021 – 603.7 mm (Fig. 1).

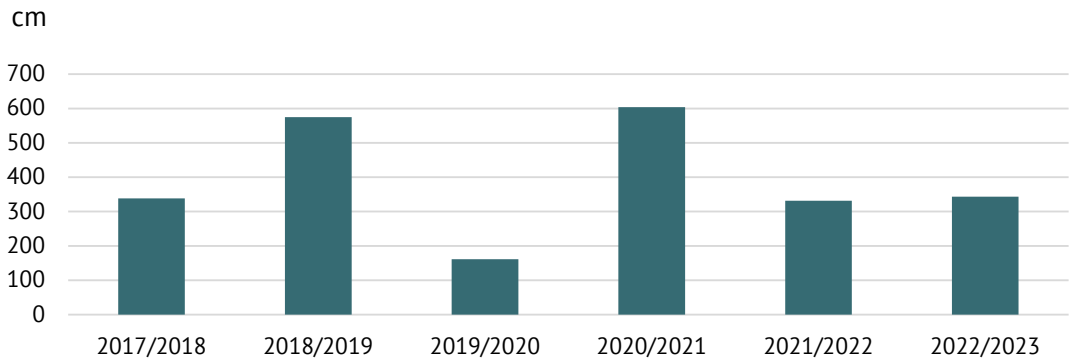

Figure 1. *Amount of precipitation (mm) during the growing season of soft winter wheat plants, 2017/2018-2022/2023*
Source: *developed by the authors*

Thus, the most favourable weather conditions were in 2018/2019 and 2020/2021, and the least favourable – in 2019/2020. Such contrasting conditions allowed the authors to study the influence of weather conditions on the formation of plant height, internode length, lodging resistance and grain productivity of the studied winter bread wheat varieties. Mathematical processing of the research results was performed using one-factor analysis of variance. The scale of R.E. Chaddock (Emmet & Chaddock, 1928) was used to assess the closeness of the relationship between the studied indicators. The value of the correlation coefficient can be used to estimate the strength of the relationship on the following scale: 0.1-0.3 – weak, 0.3-0.5 – moderate, 0.5-0.7 – significant, 0.7-0.9 – high, 0.9-0.99 – very high.

The experimental studies of plants (both cultivated and wild), including the collection of plant material, were in accordance with institutional, national or international guidelines. The authors adhered to the standards of the Convention on Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS AND DISCUSSION

On average, over the six years of research (2017-2023), medium-sized soft winter wheat varieties of Kvitka poliv (108.6 cm), Legend of Bila Tserkva (106.9 cm) and MIW Assol (103.1 cm) formed 7.5-14.0% higher plant height than short-stemmed varieties (Kraevid, Mudrist Odeska, Ozerna, Duma Odeska, Staleva, Koshova, Zdobna, Dyvo, Maria, Pamyati Hirka) and by 18.6-23.8% more than semi-dwarfs (MIW Valencia, Katarina, Centurion, Felix, PONTICUS, Faustus, Glaucus) (Fig. 2).

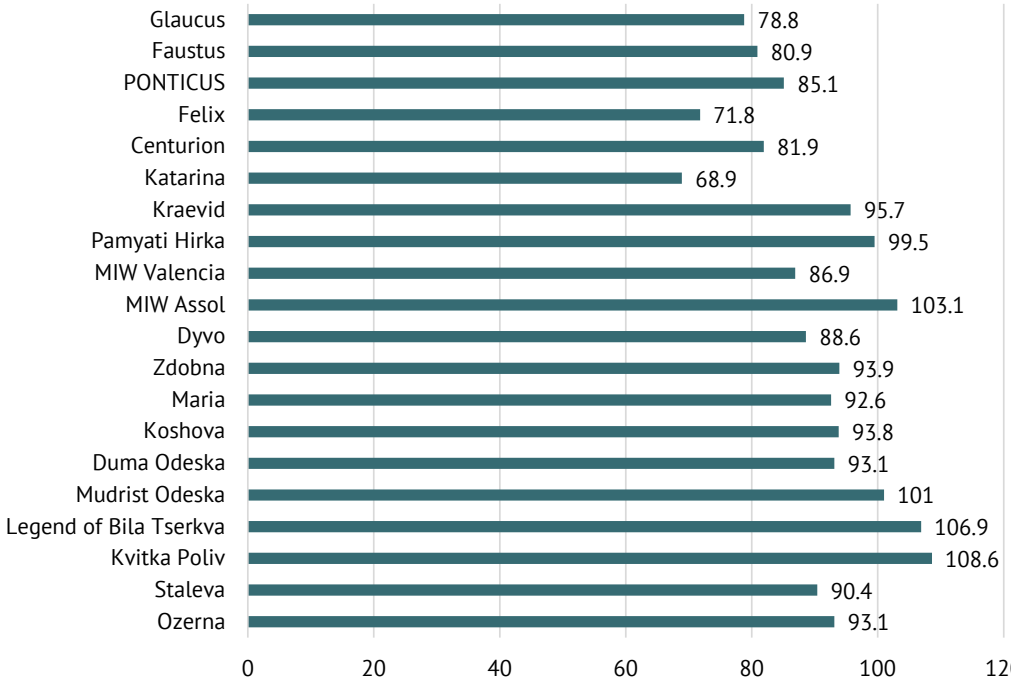

Figure 2. *Influence of varietal features on the height of soft winter wheat plants (cm), average for 2017-2023*
Source: *developed by the authors*

The lowest plant height on average for 2018-2023 was formed by semi-dwarf varieties: MIW Valencia (86.9 cm), PONTICUS (85.1 cm), Faustus (80.9 cm), Centurion (81.9 cm), Glaucus (78.8 cm), Katarina (68.9 cm) and Felix (71.2 cm). Medium-sized soft winter wheat varieties Kvitka Poliv, Legend of Bila Tserkva and MIW Assol had above average and high lodging resistance at the level of 7.0-8.2 points over the years of research, while short-stemmed varieties Maria, Mudrist Odeska, Ozerna, Pamyati Hirka, Duma Odeska, Staleva, Koshova, Zdobna, Dyvo, Kraevid had lodging resistance ranging from 6.5 to 9.0 points. Resistance to lodging of semi-dwarf varieties MIW Valencia, Katarina, Centurion, Felix, PONTICUS, Faustus, Glaucus was high and very high (8.7-9.0 points).

The height of the stem of winter wheat of the studied varieties ranged from 59.2 cm (Felix) to 98.8 cm (Legend of Bila Tserkva) (Table 2).

Table 2. *Indicators of lodging resistance and the main elements of productivity of soft winter wheat plants depending on the variety (average for 2017-2023)*

No.	Varieties	Stem height, see	The length of internodes, cm		The number of productive stems per 1 m^2	Mass of grain from 1 ear, g	Resistance to lying down
			the second lower	the last			
1	Ozerna	85.1	12.3	31.4	662	0.98	9.0
2	Staleva	82.1	12.1	30.4	651	1.02	9.0
3	Kvitka Poliv	98.7	15.5	32.1	663	1.00	7.7
4	Legend of Bila Tserkva	98.8	16.5	30.5	649	0.99	7.0
5	Mudrist Odeska	90.9	12.8	32.2	642	1.09	7.8
6	Duma Odeska	84.5	12.1	33.1	634	1.13	6.8
7	Koshova	85.6	12.2	29.5	618	1.07	6.8
8	Maria	84.7	12.4	30.1	615	1.05	8.0
9	Zdobna	85.7	12.0	32.2	640	1.05	6.5
10	Dyvo	80.6	12.2	33.3	621	1.05	9.0
11	MIW Assol	95.0	13.0	32.8	594	1.09	8.2
12	MIW Valencia	77.9	11.5	28.0	588	1.07	8.7
13	Pamyati Hirka	90.9	12.0	31.5	615	1.07	8.5
14	Kraevid	87.5	12.1	32.7	623	1.15	8.7
15	Katarina	62.1	7.9	21.2	554	0.96	9.0
16	Centurion	74.8	12.2	26.0	585	1.07	8.7
17	Felix	59.2	8.8	22.7	548	1.01	9.0
18	PONTICUS	75.2	10.2	27.0	588	1.00	9.0
19	Faustus	71.4	9.6	25.5	595	0.99	9.0
20	Glaucus	68.8	9.4	25.1	610	1.01	9.0
	Average by grade	82.0	11.8	29.2	610	1.05	8.3

Source: *developed by the authors*

The results of the research showed that the length of the second lower internode does not significantly affect the resistance to lodging of the studied winter wheat varieties. Thus, the plants of Kvitka Poliv (15.5 cm) and Legend of Bila Tserkva (16.5 cm) varieties formed a longer length of the second lower internode on average in 2017-2023, but their resistance to lodging was 7.7 and 7.0 points, respectively. The lowest (7.9 cm) was recorded in plants of the Katarina variety, whose resistance to lodging was very high – 9 points.

Shortening and thickening of the stem wall in the last (upper) internode allows avoiding yield losses due to breaking off of ears due to their excessive weight (fullness), adverse weather factors (strong winds, thunderstorms, rain, etc.) and late harvesting. Our research partially confirms this. The smallest length of the last internode of winter wheat plants was formed in foreign-bred varieties – Katarina (21.2 cm); Felix (22.7 cm), Glaucus (25.1 cm); Faustus (25.5 cm); Centurion (26.0 cm) and PONTICUS (27.0 cm), while the resistance to lodging of these varieties was 8.7-9.0 points. The length of the last internode of the straw of plants of Ozerna, Staleva and Dyvo varieties was 30.4-33.3 cm, which is 4.1-14.0% more than the average for six years, but their resistance to lodging was very high (9 points).

No less important is the sowing density, which determines the resistance to lodging. More resistant to lodging (9 points) were winter wheat varieties (Felix, Katarina, PONTICUS, Faustus, Glaucus, Dyvo, Staleva,

Ozerna) with a density of productive stem of 548-662 plants/m^2. It was found that a smaller number of productive stems (618-663 pcs. per 1 m^2) were formed by plants of the varieties Zdobna, Duma odeska, Koshova, Legend of Bila Tserkva, Kvitka poliv and Mudrist odeska, whose resistance to lodging was 6.5-7.8 points. Thus, the smallest productive stem stand (554 units/m^2) was formed in plants of the Katarina variety, and the largest – 663 units/m^2 in plants of the Kvitka Poliv variety.

An important indicator of the yield structure is the grain weight of one ear, which also affects the lodging of the crop. The optimal size of the average grain weight in an ear varies and increases significantly with the emergence of new varieties. On average, over the years of research, a larger grain weight per ear was formed by winter wheat plants of the varieties Kraevid (1.15 g), Duma Odeska (1.13 g), MIW Assol (1.09 g), MIW Valencia (1.07 g), Pamyati Hirka (1.07 g) and Centurion (1.07 g). The lower weight of grain per ear was formed by Ozerna (0.98 g/ear), Faustus (0.99 g/ear), and Legend of Bila Tserkva (0.99 g/ear).

Previous studies have shown that awned varieties have less resistance to lodging than awnless varieties (Korkhova *et al.,* 2022). Current research partially confirms this. The awned varieties Mudrist Odeska, Ozerna, Duma Odeska, Staleva, Koshova, Zdobna, Maria, Dyvo, Pamyati Hirka, Centurion, MIW Valencia, Kraevid formed 0.3 points more resistance to lodging than the awnless varieties MIW Assol, Kvitka Ooliv, Katarina, Legend of Bila Tserkva, Felix, Faustus, PONTICUS, Glaucus.

The length of the ear depends more on the varietal characteristics. The most important environmental factors are temperature, illumination and daylight hours. Lower temperatures will slow down the growth process. The ears become longer, so the yield potential increases. The largest average spike length over six years was observed in winter wheat plants of Glaucus (10.0 cm), Mudrist Odeska (10.1 cm) and Felix (12.6 cm), and the smallest in Centurion (7.1 cm) and Katarina (6.8 cm) (Table 3).

Table 3. *The influence of varietal characteristics on elements of wheat ear productivity mild winter (average for 2017-2023)*

No	Varieties	Spike length, cm	The number of ears in an ear, pcs./ear	The number of grains in an ear, pcs./ear	Weight of 1000 grains, g
1	Ozerna	8.0	13.4	27.5	40.2
2	Staleva	8.3	16.2	33.1	40.3
3	Kvitka poliv	9.9	15.0	31.1	38.0
4	Legend of Bila Tserkva	8.1	15.6	30.1	38.3
5	Mudrist odeska	10.1	16.4	32.0	38.1
6	Duma odeska	8.6	16.9	35.6	37.4
7	Koshova	8.2	18.5	31.5	36.6
8	Maria	7.9	17.9	30.6	37.1
9	Zdobna	8.2	16.1	29.6	38.4
10	Dyvo	8.0	15.7	34.3	39.1
11	MIW Assol	8.1	16.4	33.8	41.3
12	MIW Valencia	9.0	17.2	36.8	40.4
13	Pamyati Hirka	8.6	16.9	35.6	38.6
14	Kraevid	8.2	16.2	28.9	39.1
15	Katarina	6.8	14.2	25.3	40.7
16	Centurion	7.1	14.4	30.8	41.8
17	Felix	12.6	16.0	28.6	39.2
18	PONTICUS	9.9	15.4	29.1	39.3
19	Faustus	9.5	14.4	28.8	38.7
20	Glaucus	10.0	14.1	29.1	39.0
Average by grade		8.7	15.8	31.1	39.1

Source: *developed by the authors*

The main stage of plant growth is the period during which the number of ears is established. The process of spikelet differentiation in wheat occurs at the fourth stage of organogenesis, from the end of tillering to the beginning of heading. Each variety is characterized by a certain number of ears. Some varieties have a low number of ears, while others have a high number of ears. On average, in 2017-2023, the highest number of spikelets per ear was formed by Duma Odeska (16.9 spikelets/ear), MIW Valencia (17.2 spikelets/ear), Maria (17.9 spikelets/ear) and Koshova (18.5 spikelets/ear), and the lowest number of spikelets per ear was 13.4

spikelets/ear in Ozerna, which is 15.2% less than the average number of spikelets per ear for all studied varieties. It was determined that the average number of grains per ear of the studied varieties ranged from 25.3 pcs/ear (Katarina) to 36.8 pcs/ear (MIW Valencia). Thus, the varieties MIW Valencia (36.8 seeds/spike), Pamyati Hirka (35.6 seeds/spike), Duma Odeska (35.6 seeds/spike) formed 14.5-18.3% more grains per spike than the average number of varieties.

Higher yields are achieved due to the formation of better grain filling, i.e. larger, more developed grains, at the later stages of plant growth and development. Grain filling is best characterized by the weight of 1000 grains. On average, over the years of research, the weight of 1000 grains was 39.1 g. This indicator was higher in the varieties Centurion (41.8 g), MIW Assol (41.3 g), Staleva (40.3 g) and Ozerna (40.2 g). The lowest weight of 1000 grains was formed by the variety Koshova (36.6 g).

According to the results of the research, it was determined that the highest grain yield (6.88 t/ha) on average for 2017-2023 was formed by winter wheat plants of the Duma Odeska variety (6.68 t/ha), which is 5.4% more than in the Staleva variety; 6.0% more than in the Kraevid and Pamyati Hirka and Mudrist odeska varieties; 6.6% more than in the Zdobna variety; 7.0% more than in the Koshova variety; 7.3% more than in the Dyvo variety; 7.6% more than in the Ozerna variety; 9.0% more than Kvitka Poliv and Maria; 10.2% more than MIW Valencia; 10.8% more than Glaucus; 11.7% more than MIW Assol; by 12.1% than in the variety Legend of Bila Tserkva; by 13.8% than in the variety PONTICUS; by 14.7% than in the variety Faustus; by 20.5% than in the variety Felix; by 22.6% than in the variety Katarina (Table 4).

Table 4. *Winter wheat grain yield losses from lodging and shedding depending on the variety, average for 2017-2023*

No.	Varieties	Biological yield, t/ha	Actual yield, t/ha	Crop losses, %
1	Ozerna	6.49	6.17	-4.9
2	Staleva	6.64	6.32	-4.8
3	Kvitka Poliv	6.63	6.08	-8.3
4	Legend of Bila Tserkva	6.43	5.87	-8.7
5	Mudrist Odeska	7.00	6.28	-10.1
6	Duma Odeska	7.16	6.68	-6.7
7	Koshova	6.61	6.21	-6.1
8	Maria	6.46	6.08	-5.9
9	Zdobna	6.72	6.24	-7.1
10	Dyvo	6.52	6.19	-5.1
11	MIW Assol	6.47	5.90	-8.8
12	MIW Valencia	6.29	6.00	-4.6
13	Pamyati Hirka	6.58	6.28	-12.3
14	Kraevid	7.16	6.28	-12.3
15	Katarina	5.32	5.17	-2.8
16	Centurion	6.26	6.00	-4.2
17	Felix	5.53	5.31	-4.0
18	PONTICUS	5.88	5.76	-2.0
19	Faustus	5.89	5.70	-3.2
20	Glaucus	6.16	5.96	-3.2
	Average by grade	6.41	6.03	-5.9
	NIR_{05} 2018		0.22	
	NIR_{05} 2019		0.25	
	NIR_{05} 2020		0.20	
	NIR_{05} 2021		0.24	
	NIR_{05} 2022		0.26	
	NIR_{05} 2023		0.15	

Source: *developed by the authors*

Thus, the resistance to lodging of wheat crops did not always affect the formation of grain yield. Thus, the varieties with high (7.7-8.7 points) and very high (9 points) resistance to lodging formed grain yields of 5.90-6.28 t/ha and 5.17-6.32 t/ha, respectively, while the varieties with medium resistance to lodging (6.5-7.0 points) formed 5.87-6.68 t/ha. Grain yield losses due to lodging and grain shattering ranged from 2.0 to 12.3% on average in 2017-2023. Correlation analysis of the relationship between lodging resistance and the number of productive plant stems, ear weight and grain yield of the studied winter wheat varieties over

six years of research showed that there was no relationship for a number of varieties Ozerna, Staleva, Dyvo, Katarina, Felix, PONTICUS, Faustus and Glaucus.

For the varieties Legend of Bila Tserkva (r=-0.89), Koshova (r=-0.78), Zdobna (r=-0.72), MIW Valencia (r=-0.90), Pamyati Hirka (r=-0.94) and Kraevid (r=-0.90) and Centurion (r=-0.92), a high and very high inverse relationship between lodging resistance and the number of productive stems per unit area was found, for MIW Assol varieties (r=-0.67), Mudrist Odeska (r=-0.61), Maria (r=-0.60), Duma Odeska (r=-0.55), a significant inverse relationship was found, and for Kvitka Poliv (r=-0.49) – a moderate inverse relationship (Table 5). That is, with an increase in the number of productive stems per 1 m^2, there is a decrease in lodging resistance of most winter wheat varieties.

Table 5. *Correlation analysis between dormancy and indicators of the main elements of the productivity of winter wheat plants of different varieties*

No.	Varieties	Performance elements		
		number of productive stems, pcs./m^2	mass of grain from 1 ear, g	yield, t/ha
1	Kvitka poliv	r=-0.49	r=-0.79	r=-0.73
2	Legend of Bila Tserkva	r=-0.89	r=0.11	r=-0.31
3	Mudrist odeska	r=-0.61	r=-0.57	r=-0.41
4	Duma odeska	r=-0.55	r=-0.24	r=-0.33
5	Koshova	r=-0.78	r=-0.32	r=-0.61
6	Maria	r=-0.60	r=-0.26	r=-0.50
7	Zdobna	r=-0.72	r=0.12	r=-0.41
8	MIW Assol	r=-0.67	r=0.11	r=-0.16
9	MIW Valencia	r=-0.90	r=0.42	r=-0.18
10	Pamyati Hirka	r=-0.94	r=0.21	r=-0.56
11	Kraevid	r=-0.90	r=0.55	r=-0.15
12	Centurion	r=-0.92	r=0.46	r=-0.22

Source: *developed by the authors*

A weak direct correlation between resistance to lodging and grain weight per 1 ear was established for plants of varieties Legend of Bila Tserkva (r=0, 11), Zdobna (r=0.12), MIW Assol (r=0.11) and Pamyati Hirka (r=0.21), moderate for MIW Valencia (r=0.42), Centurion (r=-0.46) and significant for Kraevid (r=0.55). A high and significant inverse correlation between these indices was found for Kvitka Poliv (r=-0.79) and Mudrist Odeska (r=-0.57); moderate – for Koshova (r=-0.32) and weak – for Duma Odeska (r=-0.24) and Maria (r=-0.26). For all the studied winter bread varieties, there is an inverse correlation between resistance to lodging and yield, which ranges from weak – r=-0.15-0.22 (MIW Assol, MIW Valencia, Kraevid, Centurion) to high – r=-0.73 (Kvitka Poliv). Thus, the studies have established the influence of varietal characteristics of winter wheat on the formation of plant height, resistance to lodging, productivity elements and grain yield. The highest grain yield was formed by the variety Duma odeska, which is 6.68 t/ha with high resistance (7.8 points) to lodging and high yield losses from lodging and shattering (10.2%).

The research conducted by V.A. Vlasenko *et al.* (2018) with 50 varieties of winter wheat showed that the shorter the growing season of genotypes, the shorter the plants, which is also confirmed by our own research. It was determined that among the 20 varieties studied, the mid-season varieties Kvitka Poliv, Legend of Bila Tserkva and MIW Assol formed the highest plant height (103.1-108.6 cm), and the lowest was formed by semi-dwarf varieties (68.9-86.9 cm) – MIW Valencia, PONTICUS, Faustus, Centurion, Glaucus, Katarina, and Felix.

Plant height plays a very important role in the formation of grain yields, and is at the same time an important component of the resistance of cereal plants to lodging. According to the research of W-G. Li *et al.* (2022) found that lodging resistance varies greatly depending on the plant height of each variety. Therefore, it is necessary to take this into account when selecting varieties for different soil and climatic growing conditions, agrophones and predecessors. Current research confirms this statement. Thus, the medium-sized varieties Kvitka Poliv, Legend of Bila Tserkva and MIW Assol had above average and high resistance to lodging (7.0-8.2 points) during all years of research, while in short-stemmed varieties the resistance to lodging ranged from 6.5 to 9.0 points.

L. Wang *et al.* (2022) state that with decreasing plant height of winter wheat, productivity increases. Ye. Zaika (2021), F. Spolidorio (2019) argue that short winter wheat varieties are a source of redistribution mechanisms that affect plastic matter, so that tall varieties with high stem strength can outperform short varieties of yield. Current research confirms this. Thus, on average, over the years of research (2017-2023), the winter wheat variety Duma Odeska has a maximum yield of 6.88 t/ha, which is 0.88-1.71 t/ha higher than the

semi-dwarf wheat varieties Centurion, MIW Valencia, Felix, Katarina, Faustus, PONTICUS and Glaucus.

The high grain yield of winter wheat is influenced by the interaction of many factors, namely the number of productive stems, thousand grain weight and grain quality (Tsvey *et al.,* 2021). M. Lozinskiy *et al.* (2021) determined that grain quality or productivity largely depends on the components caused by the action and interaction of genetic factors, so the main ear plays a key role in shaping grain productivity and wheat grain yield.

According to the research of M. Korkhova *et al.* (2022) conducted during 2020-2022 with winter wheat varieties, the largest weight of 1000 grains was formed when growing the variety Duma odeska, which averaged 37.2 g, which is 0.2 g less than in the current research. Research by Bazalii *et al.* (2019) showed that in the South of Ukraine, it is necessary to grow plastic wheat varieties with increased yield stability (Odesa, Kherson Bezosta, Clarissa, Kherson 99, Nakhidka Askaniyska) if there are strict stress limits. Plant height plays a major role in the resistance of cereals to lodging (Rachon *et al.,* 2020). Plant height is closely related to lodging resistance at all stages of cereal development. Varieties with high lodging resistance are better than those with low lodging resistance because they are able to withstand lodging pressure.

T. Makoveychuk *et al.* (2018) determined that lodging of cereals, especially high-yielding wheat crops, is one of the main factors limiting the high yield. Losses of winter wheat grain yield due to lodging can be in the range of 10-80 % due to deterioration of harvesting conditions. A. Zhupina *et al.* (2021) found that in many populations of winter wheat, there is a high interdependence between ear grain weight and grain yield (r=0.624...0.803), which suggests the prospects of selecting for yield by the "ear grain weight" indicator.

Thus, since the studies were conducted in years with different climatic conditions, there is no consensus among scientists on the influence of different morphological traits on lodging resistance and grain yield formation of soft winter wheat varieties. With the emergence of new varieties of production, this issue requires further research.

CONCLUSIONS

According to the results of field and laboratory studies conducted during 2018-2023 in the Southern Steppe of Ukraine, a significant influence of varietal characteristics on the formation of plant height, stem length, second and last internodes of winter bread wheat, number of productive stems per 1 m^2, grain weight per ear and lodging resistance was found. Resistance to lodging of wheat crops did not always affect the formation of grain yield. The varieties with high (7.7-8.7 points) and very high (9 points) resistance to lodging produced grain yields of 5.90-6.28 t/ha and 5.17-6.32 t/ha, respectively, while the varieties with medium resistance to lodging (6.5-7.0 points) produced 5.87-6.68 t/ha. Grain yield losses due to lodging and grain shattering ranged from 2.0 to 12.3% on average over the years of research.

The highest productivity was recorded in the varieties of Ukrainian breeding Mudrist Odeska (6.28 t/ha) and Duma Odeska (6.68 t/ha), created at the Selection and Genetic Institute – the National Centre for Seed Science and Variety Studies of the National Academy of Agrarian Sciences; Pamyati Hirka (6.28 t/ha) and Kraevid (6.28 t/ha) – National Research Centre "Institute of Agriculture of the National Academy of Sciences of Ukraine" and Staleva (6.32 t/ha) and Ozerna (6.17 t/ha) – Bor Farm. With the increase in the number of productive stems per 1 m^2, the lodging resistance of most winter wheat varieties decreased. The most resistant to lodging were (Felix, Katarina, PONTICUS, Faustus, Glaucus, Dyvo, Staleva, Ozerna) with a density of productive stems of 548-662 pcs./m^2, and less resistant to lodging were (Zdobna, Duma Odeska, Koshova, Legend of Bila Tserkva, Kvitka Poliv and Mudrist Odeska) with the number of productive stems 618-663 pcs./m^2.

Correlation analysis of the relationship between the lodging resistance index and the number of productive plant stems, ear weight and grain yield of the studied winter wheat varieties during six years of research showed that there is no relationship for a number of varieties Ozerna, Staleva, Dyvo, Katarina, Felix, PONTICUS, Faustus and Glaucus. A high and very high inverse relationship between lodging resistance and the number of productive stems per unit area was found for the varieties Legend of Bila Tserkva, Koshova, Zdobna, MIW Valencia, Pamyati Hirka, Kraevid and Centurion. A high and significant inverse correlation between lodging resistance and grain weight per ear was found for Kvitka Poliv and Mudrist Odeska. For all tested winter bread wheat varieties, there is an inverse correlation between lodging resistance and yield, which ranges from weak to high. In the future, it is planned to characterize the effect of weather conditions and characteristics of winter wheat varieties on grain quality, which will provide a more complete description of the winter wheat varieties under study.

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CONFLICT OF INTEREST

There is none.

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Вплив сортових особливостей пшениці озимої та погодних умов на стійкість до вилягання та продуктивність

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Анотація. Технології вирощування, вибір сорту є вирішальним чинником підвищення врожайності та покращення якості зерна пшениці озимої. Посівні площі пшениці озимої посідають перше місце в Україні, з чим пов'язане виробництво якісного зерна. Метою роботи було визначити вплив погодних умов та особливостей сорту на висоту рослин пшениці озимої, довжину міжвузлів, стійкість до вилягання, коефіцієнт продуктивності та врожайність протягом досліджуваних років. У процесі дослідження застосовувалися загальноприйняті методи: системний підхід, підхід системного аналізу, підхід аналітичного синтезу, польовий підхід та статистичний підхід. У статті наведено дані про результати проведених досліджень із 20 сортами пшениці м'якої озимої в умовах Навчально-практичного центру Миколаївського національного аграрного університету з 2017 по 2023 роки. Агротехніка вирощування сортів пшениці озимої широко поширена в степах півдня України. Досліджено вплив погодних умов та сортових особливостей на стійкість до вилягання та продуктивність пшениці озимої. Результати показали, що оптимальна висота рослин сортів

пшениці озимої становила від 82,1 до 84,5 см, а найвища урожайність – 6,32 т/га у сорту Сталева та 6,68 т/га у сорту Дума Одеська. Встановлено достовірний вплив сортових ознак на довжину стебла, друге та останнє міжвузля, кількість стебел, що утворюються на 1 м^2, масу зерна в колосі та стійкість до вилягання пшениці м'якої озимої. Рослини досліджуваних сортів пшениці м'якої озимої Сталева, Диво, Катаріна, Фелікс, Озерна, ПОНТІКУС, Фауст, Глаукус мають дуже високу (9,0 балів) стійкість до вилягання незалежно від погодних умов року. Вищу продуктивність досягли українські сорти Дума Одеська (6,68 т/га) та Сталева (6,32 т/га). Одержані наукові результати досліджень сприяють широкому використанню досліджуваних сортів пшениці озимої в цій обґрунтовано-кліматичній зоні та сприяють подальшому вдосконаленню виробництва зерна

Ключові слова: висота рослин; довжина міжвузлів; довжина колоса; кількість продуктивних стебел; маса 1000 зерен; пшениця м'яка озима; сума опадів