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Productivity of winter rape depends on the morphostructure of plants in the conditions of the Steppe of Ukraine

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Abstract. The aim of the study was to determine the morpho-structural indicators of the productive organs of winter rapeseed that influence yield, and to establish, on this basis, a strategic direction for the development of a promising assortment for cultivation in the conditions of the Southern Steppe of Ukraine. Using the hybrids Dario, Oriolus, and Blackstone (produced by VNS), a comparative analysis was conducted of the morpho-structure of vegetative and generative plant organs and their influence on yield. It was noted that the seed purity used in the study was 100.0%, and laboratory germination ranged from 91.6% to 94.0%. The total number of shoots at harvest time was largely determined by the biological properties of the hybrid and varied within the range of 9.8 to 15.3 shoots per plant. It was substantiated that the productivity of the crops was primarily determined by the number of pods on first-order branching shoots, which accounted for 75.7-78.5% of the total number of pods, depending on the biological characteristics of the hybrids. The number of pods located on the shoots of zero and second-order branching was minimal, amounting to 12.8% and 9.5%, respectively. The average weight of 1,000 seeds showed no significant difference among the studied hybrids, ranging between 3.69 and 3.81 grams. Differences in yield among the hybrids were determined by a combination of productivity indicators, particularly the total number of pods per plant and the number of seeds per pod. The highest number of pods was observed in the Dario hybrid – 249.4 pods per plant, and the lowest in the Blackstone hybrid – 198.8 pods per plant. The Dario hybrid demonstrated the most optimal plant morpho-structure, contributing not only to the highest yield (4.89 t/ha) but also to the greatest realisation of the hybrid's biogenetic potential (69.9%). Lower comparative indicators were observed in the Blackstone hybrid, with yield and biogenetic potential realisation at 3.11 t/ha (56.6%), respectively

Keywords: rapeseed hybrid; plant morpho-structure; branching; pod; seed; yield

INTRODUCTION

One of the most profitable oilseed crops in Ukraine is rapeseed (*Brassica napus* L.), which is due to the consistently high prices for its seeds and processed products. The expansion of rapeseed production in the Southern Steppe of Ukraine is a promising area of agricultural activity that will help improve the economic efficiency of farms and support the development of bioenergy in the context of climate change. One of the key and

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significant reserves for increasing the efficiency of rapeseed production is the introduction of modern hybrids and varieties that are characterised by high yields and sufficient adaptation to local soil and climatic conditions. The relevance of the research is driven by the need to optimise the assortment of winter rapeseed and is focused on identifying the morpho-structure of productive plant organs that influence yield.

Much of the current scientific research in the field of rapeseed production is aimed at improving the traditionally basic elements of production in different soil and climatic zones of Ukraine. For entrepreneurs, the components of winter rape yield are presented in sufficient detail, taking into account the duration of the phases of plant growth and development at optimal temperatures, pesticide use, disclosure of agrotechnical aspects of production, such as sowing, germination, vegetation period, budding and flowering stages, crop care, ripening, and harvesting. Considering the experimental material obtained, the technological components of commercial crop production are scientifically and reasonably substantiated: the feasibility of a differential approach to soil cultivation, the use of mineral fertilisers, feeding areas, growth regulators, etc.

O.V. Kurach (2021) observed that Ukraine's natural conditions enable the biogenetic potential of winter rape to be realised. Provided the main elements of the technological process are adhered to, it is possible to obtain seed yields of 5.0-6.0 t/ha. However, due to climate change, the average rapeseed yield on many farms is 1.7-2.8 t/ha. M.V. Minkin & G.O Minkina (2023) found that, in southern Ukraine and under natural moisture conditions, the yield of winter rape is 1.5-1.9 t/ha. The agroclimatic and soil conditions in this region allow winter rape to be grown with a yield of 1.8-1.9 t/ha under natural moisture conditions. A.A. Shevchenko & T.O. Vasylinych (2022) also noted that the Odesa Region leads Ukraine in rapeseed production, with a sown area exceeding 100 thousand hectares and a gross harvest accounting for 9.1% of Ukraine's total.

Scientist S.V. Vasylenko (2024) emphasised that the use of new hybrids resistant to adverse factors will significantly increase production productivity. However, in order to obtain stable and high results, it is necessary to introduce innovative technologies that play a significant role in rapeseed cultivation, including paying attention to environmental factors that will reduce the negative impact on the environment by pesticides and mineral fertilisers. Researchers V.M. Bezkorovaynyi & V.V. Moisienko (2024a) noted that in the conditions of the Right-Bank Forest-Steppe, the improvement of only certain elements of the technological process (increasing row spacing) contributed to the production of 3.82-4.45 t/ha of seeds. The best hybrids in terms of yield and individual productivity indicators were the Exception (BAYER) and InVigor 1030 (BASF) hybrids. One of the main indicators that determine the individual productivity of a plant is the presence of generative components. Sparse plant placement allows up to 430-450 pods to be formed per plant, and the average weight of 1,000 seeds is 6.0-6.4 g. A significant reserve for increasing rapeseed yields is the use of bioregulators and fertilisers. S. Muntyan (2024), studying the effect of a nitrification inhibitor (NI) at different rates of nitrogen fertilisers and the application of urea-ammonia mixture on the yield of winter rape seeds, found a significant increase in yield compared to the variant without inhibitors and fertilisers.

At present, the Catalogue of plant varieties suitable for distribution in Ukraine (2025) includes 378 samples of winter rape in the Polissya, Forest-Steppe, and Steppe zones. Scientists O.P. Tkachuk *et al.* (2024) pointed out that such a wide variety of varieties creates some confusion for entrepreneurs in determining the optimal varietal composition. It is also noted that hybrids provide one and a half times higher yields of winter rape seeds than varieties. However, to obtain a high yield, it is necessary to apply much more fertiliser and strictly adhere to the timing of agricultural activities. Researchers A.V. Kostenko *et al.* (2023) noted that winter rape is one of the main technical and fodder crops. Breeding programmes for winter rape are aimed at creating high-yielding, large-seeded varieties and hybrids with wide adaptability to a range of abiotic factors that can fully realise their biogenetic potential in the face of climate change. The aim of this study was to investigate the structure of the productive organs of winter rape, which determine its yield, and, based on the results obtained, to develop strategic recommendations for the development of promising varieties suitable for cultivation in the Southern Steppe of Ukraine.

MATERIALS AND METHODS

The experiment to study the peculiarities of the formation of the morphological structure of winter rape plants of Dario, Oriolus and Blackstone hybrids was conducted at the Educational and Research Centre of Mykolaiv National Agrarian University (NAU) in 2021 and 2022. During the growing seasons 2021-2022 and 2022-2023, the formation of plant morphological structures and their influence on yield were studied. The surveys were carried out on 100 plants (4 replications of 25 plants each). The biometric characteristics of pods and seeds were determined on 400 samples (100 samples in 4 replications). The material for the research was winter rape (*Brassica napus* L.) hybrids Dario, Oriolus and Blackstone. Experimental studies of plants were carried out in accordance with national guidelines (Law of Ukraine No. 4147-IX, 2024).

Dario. A hybrid of winter rape from DSV. It is characterised by intensive development of the root system in autumn. It has genetic resistance to pests, which makes it possible to quickly regenerate damaged plant tissue. Resistant to phomosis due to the RLM 7 gene. Demonstrates excellent indicators of developmental stability and yield. Plants of the hybrid form a strong leaf apparatus of medium size. The maturity group is medium late. The designation group is oilseed. The growing season is 292-320 days. Plant height is 175 cm. It shows a high oil content. Yield potential is 7.0 t/ha. The resistance to cold is 8. Drought resistance is 9. The index of the resistance to lodging is 9. The resistance to major diseases of rapeseed is 8. It is suitable for late sowing. The recommended zone for cultivation is the Forest-Steppe of Ukraine.

Oriolus. A hybrid of winter rape from DSV. It is high-yielding short-stemmed hybrid. It has high stability when grown in different soil and climatic conditions. It effectively uses spring moisture reserves. It has high winter hardiness. It is characterised by early flowering and ripening. The maturity group is medium-late. The designation group is oilseed. The growing season is 292-320 days. Plant height is 165 cm. It obtains high oil content. The yield potential is 6.6 t/ha. The index of the resistance to cold is 8. The drought resistance is 9. The index of the resistance to lodging is 9. The resistance to phomosis is 8. It is suitable for early sowing and for cultivation throughout Ukraine.

Blackstone. A hybrid of winter rape from VNIS. It is a high-yielding short-stemmed hybrid. It has high winter hardiness due to its low tendency to stem growth in autumn, so it is suitable for early sowing. It has a fairly high resistance to lodging and high synchronisation of pod and stem ripening. The maturity group is medium late. The designation group is oilseeds. The growing season is 292-323 days. Plant height is 165 cm. It obtains high oil content. The yield potential is 5.5 t/ha. The index of the resistance to cold is 8.5. The drought resistance is 8.5. The index of the resistance to lodging is 8.5. The resistance to phomosis is 8. It is suitable for cultivation throughout Ukraine.

The agrotechnics of winter rape cultivation was implemented in the experiment in accordance with zonal recommendations for growing oilseeds in the Steppe zone of Ukraine. Rapeseed was sown after peas harvested in late June (third decade). Immediately after harvesting the predecessor, soil preparation for sowing winter rape began which consisted of disking to a depth of 12-15 cm and two subsequent disks to a depth of 5-6 cm. 3 days before sowing, the soil was levelled with a compactor and water-charging irrigation was carried out by sprinkling at the rate of 350 m^3/ha. Sowing of winter rape hybrid seeds was carried out on 29-30 August using a conventional grain seeder SZ-6 with coil seeders for small seeds and a distance of 15 cm between the coulters at the rate of 500 thousand germinating seeds per 1.0 ha to a depth of 2-3 cm. The plots were 300 m^2 (6×50 m) in size and orientated from east to west. Seeds were removed from the seeder cans each time with a vacuum cleaner, after which the seeder passed 100 m without seeds and 300 m with seeds of the next plot. That technological method excluded the possibility of variety mixing which was later confirmed during the crop inspection. Before disking, 100 kg of ammophos (N:P – 12:52) was applied. In the spring, 150 kg/ha of ammonium sulphate (N:S – 21:24) and 300 kg/ha of ammonium nitrate (N:P – 34:0) were applied to the frozen soil. Foliar feeding with boron was carried out twice: in autumn on a well-developed rosette – 1 l/ha (B11 %) and in spring during the budding phase at the same rate. Zinc was applied as part of a complex micronutrient fertiliser on the leaves, g/l (N – 80; MgO – 33; Fe – 4.0; Mn – 13.4; B – 5.4; Zn – 8.0; Cu – 3.0; in spring at a plant height of 20-25 cm at a rate of 1.0 l/ha.

The field for sowing rapeseed was not clogged with weeds, which justified the complete refusal to use herbicides. Growth control was carried out with a preparation with the active ingredient tebuconazole (250 g/l) in autumn at the stage of 6-7 leaves at a rate of 0.6 l/ha, and in spring at a plant height of 20-25 cm for greater shoot branching at a rate of 0.8 l/ha. Fungicidal protection was applied at the beginning of budding with a preparation containing the active ingredient metconazole + pyraclostrobin (130 g/l + 80 g/l) at a rate of 0.7 l/ha. To control the spread of pests, yellow containers – traps – were installed at the demonstration site to determine the thresholds of harmfulness and the timing and effectiveness of insecticide application. Observations of pest reproduction showed that the use of insecticide protection was appropriate. Due to the optimal sowing time and distance from the agrocenoses of cabbage crops, it was sufficient to carry out only one treatment in autumn (a preparation based on chlorpyrifos – 500 g/l + cypermethrin – 50 g/l at a rate of 1 l/ha). In the autumn period, the threshold of harmfulness was exceeded only by the reproduction of rapeseed flea beetle (*Psyllioides chrysocephala*).

In the spring, at the first appearance of rapeseed weevil (*Ceutorhynchus assimilis*) in the traps (III decade of March), the crops were treated with a pyrethroid preparation based on alpha-cypermethrin (100 g/l) at a rate of 0.2 l/ha. When the plants reached a height of

20-25 cm, the crops were treated for the third time with a preparation based on imidacloprid 150 g/l + lambda-cyhalothrin 50 g/l at a rate of 0.15 l/ha. At this time, individuals of cabbage whitefly (*Pieris brassicae*) and rapeseed sawfly (*Athalia rosae*) were observed in the traps. During the budding period, the crops began to be invaded by the rapeseed leaf beetle (*Entomoscelis adonidis*) and the hairy deer moth (*Epicometes hirta*), the latter being extremely widespread, with up to 40 individuals per day being trapped. The fourth insecticide treatment was carried out with a preparation based on chlorpyrifos (500 g/l + cypermethrin). During the flowering period, there was an active infestation of hairy deer and rape leaf beetle, which was controlled by treating the area at night with a mixture of bee-friendly products based on acetamiprid and tau-fluvalinate. After flowering was complete, there was little damage from the cabbage moth (*Plutella xylostella*), cabbage mosquito (*Dasineura brassicae*), and cabbage bug (*Eurydema ventralis*). Irrigation of winter rape crops by sprinkling was carried out according to zonal recommendations. Water-charging irrigation was carried out before sowing (350 m^3/ha). During the growing season, if necessary, artificial moisture was provided by sprinkling, taking into account natural precipitation (350-450 m^3/ha).

The experimental field of Mykolaiv NAU is located in the central agroclimatic region. It is characterised by long warm summers, short winters with little snow, insufficient precipitation, and a large amount of solar radiation. Spring is short (March-April). The average monthly temperature in April is 10.9°C. Summers are long (May-September), dry, hot, and cloudy. The average monthly temperature in July is 24.3°C. Autumn is short (October-November). The average monthly temperature in October is 11.1°C. Winters are short (December-February), with frequent thaws. The average monthly temperature in January is -1.7°C. The sum of active temperatures during the active growing season (above 10.0°C), which lasts 70-200 days, is 2,900-3,600°C. The average duration of the frost-free period is 175-215 days. The southern region of Ukraine is suitable for growing a wide variety of field crops, including winter rape, due to its soil and climatic conditions. Warm winters, long autumns and springs contribute to the full development of growth processes in both spring and winter crops. However, in summer, there is an increase in air temperature and soil surface that exceeds the optimal parameters, which does not allow agricultural plants to realise their biogenetic potential (Vozhegova *et al.*, 2025).

The soils of the experimental field of the NSCP of Mykolaiv NAU are represented by southern chernozems, characterised by moderate nutrient supply and suitable for growing crops. Comparison of the physical and chemical parameters of the soil of the experimental plot with the optimal parameters and grouping of soils by properties established by DSTU 4362:2004 (2005) allowed to conclude that these soils are suitable for growing all crops recommended for the Southern Steppe. The nature of the supply of basic nutrients was as follows: NO_3 + NH_4, mg/kg – average; P_2O_5, mg/kg – average; K_2O, mg/kg – very high; Ca, mg-eq/100 g – increased; Mg, mg-eq/100 g – average; humus, % – increased; physical clay content, % – close to optimal; pH (KCl) – 5.7. High sustainable yields in the steppe zone depend on the level of moisture, so in rainfed conditions, measures to increase their productivity should be aimed at accumulating moisture and improving the nutrient regime.

The weather conditions during the experimental work were at the level of long-term averages: the amount of precipitation was 350-400 mm, and the average monthly air temperature during the growing season of winter crops was 11.4°C. At the same time, in some years, the main hydrothermal indicators differed significantly from the long-term average. The growing season of 2021 was relatively cool but rainy. The average annual air temperature was 10.3°C, which is 1.1°C less than the long-term average. The 2023 was warmer. The cumulative air temperature exceeded the long-term average by 9.5°C, but precipitation was at the level of the long-term average. Certain plant growing seasons differed significantly from the long-term average in some years. The autumn period favoured the growth and development of vegetative organs with biochemical and morphological parameters that ensure the plant's adaptation to adverse weather conditions in winter. The air temperature regime in September-November 2021-22 during the initial growing season of winter rape was generally favourable for growth processes. The average monthly air temperature ranged from 15.4-15.8°C in September to 5.3-6.1°C in November, while the long-term average was 5.5°C. Total precipitation in 2021 was much higher than the long-term average. At the same time, in 2022, it was a quarter less than the long-term average. In 2023, the total amount of precipitation during the year was at the level of the long-term average. The average amount of precipitation during 2021-2023 was at the level of long-term averages. The dynamics of precipitation during the year had a specific uneven character. In the autumn period (September-November, 2021-2022), the average precipitation was 100.0 mm, 140.4 mm, while the normal precipitation was 102 mm.

Taking into account the moderate air temperatures for the season, winter rape plants developed well, which to some extent prevented their damage in winter.

In the spring (March-May), compared to the average (122 mm), there was a significant difference in the dynamics of precipitation compared to the long-term average. In the spring of 2022, only 71.4 mm fell, while in 2023 it was 198.0 mm, or 2.8 times more. Thus, natural moisture significantly influenced the formation of the leaf apparatus, the growth of the productive part of the plant during the entire period of active vegetation. The air temperature regime during the study period had, in general, a smaller deviation from the average. The average long-term air temperature was 11.4°C, the average temperature for the period of the experiment in 2021-2023 was 11.1°C, or the deviation for individual years was 0.3-1.1°C, or 6.1-10.7%. In winter, negative low air temperatures did not cause plant death, as they most often fluctuated around 0°C. Thus, the weather conditions during the experiment were at the level of long-term averages, although significant deviations were observed in some periods of plant growth and development. The influence of factors that suppress plants was not detected. Additional artificial irrigation as needed contributed to the maintenance of optimal hydrothermal conditions in the agrocenosis of winter rape.

RESULTS

The quality of field crop seeds, including winter rape seeds, significantly impacts field germination, growth energy, and the formation of the synthetic apparatus during the initial stage of plant growth. The average weight of seeds used for sowing is also important. This indicator determines the amount of reserve nutrients, positively affecting seed germination. The average weight of F1 hybrid seeds intended for sowing was 6.63 g/1,000 seeds, a fairly high value for winter rape (Table 1).

Table 1. *Sowing qualities of winter rapeseed (average for 2021-2022)*

Hybrid	Average seed weight, 1,000 seeds/g	Purity of seeds, %	Germination of seeds, %	Sowing suitability of seeds, %
Dario	7.03	100.0	93.2	93.2
Oriolus	6.60	100.0	91.6	91.6
Blackstone	6.26	100.0	94.0	94.0
Medium	6.63	100.0	92.9	92.9
NIR05	0.98	-	-	-

Source: *created by the authors*

A variety of parental forms were involved in the breeding process, which influenced not only the biometric characteristics of the plants, but also the morphological traits of the seeds, including their shape, size, and weight. The highest seed weight was recorded in the hybrid Dario, amounting to 7.03 g per 1,000 seeds. The average seed weights of the Oriolus and Blackstone hybrids were comparable, at 6.60 g/1,000 seeds and 6.26 g/1,000 seeds, respectively. However, the variation in average seed weight among the hybrids was relatively low, ranging from 4.02 to 3.72 g, or 9.1-9.4% of the mean value.

Accordingly, to achieve a uniform density of productive plants per unit area, the sowing rate should be adjusted proportionally and should not exceed the average rate by more than 10.0%. A substantial number of winter rapeseed hybrids of foreign origin (Germany, France, the Netherlands, Czech Republic) are utilised in commercial production. Breeding companies supplying the Ukrainian market provide seeds that are fully compliant with agricultural standards: they are calibrated, cleaned, and treated. Laboratory analysis confirmed that the seed purity in the experiment was 100.0%, while germination rates ranged from 91.6% to 94.0%, thus meeting the requirements for first-class seed material. Given the high sowing quality of the seeds, there is no justification for increasing the calculated seeding rate for any of the hybrids examined. Consequently, the sowing rate was set at 500,000 viable seeds per hectare, corresponding to 3.13-3.52 kg/ha.

Considering the fact that winters in Ukraine are relatively mild, with the southern region being no exception, no damage to winter rapeseed plants due to low temperatures was recorded during the winter period. The onset of vegetation resumed 8-10 days earlier than the average long-term norms. The dynamics of rapeseed phenophases was slightly ahead of schedule, taking into account the accumulation of positive temperatures in the initial period of vegetation. During the seed ripening period, more than 97.0% of winter rapeseed plants have a well-developed central stem. There is no branching in the upper part of the stem, with first-order branches extending from the lower part of the stem, and second-order branches extending from them. In the upper part, only flowers are located on the 0^{th} order branch, and later – pods. Observations have shown that the biological characteristics of the hybrid significantly influenced the condition and nature of the morphostructure of the entire above-ground part of winter rapeseed. However, some specificity is evident in a number of indicators (Table 2).

Table 2. *The branching pattern of winter rapeseed plants during the harvest period (average for 2022-2023)*

Hybrid	Number of shoots, per plant	Including the order of branching of pieces/plants		
		0^{th}	1^{st}	2^{nd}
Dario	15.3	1.0	10.4	3.9
Oriolus	12.1	1.0	8.7	2.4
Blackstone	9.8	1.0	7.1	1.7
Medium	12.4	1.0	8.7	2.7
NIR05	1.01	-	0.74	0.22

Source: *created by the authors*

The highest ability to form early-maturing axillary buds in the basal part of the shoot of the 0^{th} order of branching was observed in the Dario hybrid and amounted to 10.4 pieces per plant, the lowest – in the Blackstone hybrid (7.1 pieces per plant). A similar trend between hybrids was observed in the formation of early-maturing buds on shoots of the 1^{st} order of branching, which contributed to the growth of shoots of the 2^{nd} order of branching – 3.9 pcs/plant and 1.7 pcs/plant, respectively. Ultimately, the total number of shoots of all orders of branching on which pods are formed was highest in the Dario hybrid, reaching 15.3 per plant, and lowest in the Blackstone hybrid (9.8). An important component of winter rapeseed productivity is the number of pods per plant (Table 3).

Table 3. *Yields of winter rapeseed hybrids during the harvest period (averages for 2022-2023)*

Hybrid	Number of pods, pieces/plant	Including the order of branching of pieces/plants		
		0^{th}	1^{st}	2^{nd}
Dario	249.4	28.7	194.5	26.2
Oriolus	219.5	31.6	166.2	21.7
Blackstone	198.8	25.3	158.0	15.5
Medium	222.5	28.5	172.9	21.1
Deviation, %	10.1-11.2	11.5-14.4	75.8-79.5	7.8-10.5
NIR05	15.92	2.16	13.08	1.53

Source: *created by the authors*

The largest number of pods was observed in the Dario hybrid, amounting to 249.4 pods per plant, and the smallest number was observed in the Blackstone hybrid, amounting to 198.8 pods per plant. Among the hybrids studied, the morphostructure of pod placement also had its own characteristics. On the shoots of the 0^{th} branching, there were on average 12.8% of pods of the total number. The number of pods on the shoots of the 1^{st} order of branching was the largest and amounted to 77.7%. Taking into account the branching of hybrids, the proportion of pods on the shoots of the 2^{nd} order of branching was the smallest – 9.5%. The tendency of pod placement on shoots of different branching orders in the studied hybrids was almost the same. It should be noted that the main number of pods was located on shoots of the 1^{st} order of branching and accounted for 75.0-79.5% of the total number. That is, the biological characteristics of the crop were manifested, and the differences between the studied hybrids were insignificant. Thus, the overall localisation of pods on shoots is related to the structure of the shoots: a larger number of shoots on the plant led to an increase in the number of pods on the plant. When considering the “load” borne by the pods on individual shoots of various branching orders, a certain regularity is also observed: the largest number of pods per shoot is observed on shoots of the 1^{st} order of branching, and the smallest on shoots of the 2^{nd} order of branching, as the least developed. The variation in the indicator studied was also insignificant and ranged from 18.7 to 22.2 pieces for shoots of the 1^{st} order of branching and from 6.7 to 11.1 pieces for shoots of the 2^{nd} order of branching. Compared to the “load” of pods per shoot of the 0^{th} order of branching, an increase in the order of branching leads to a decrease in the number of pods per shoot, respectively 28.5-19.8-7.8 pieces. The number of pods formed on one plant has a significant impact on the formation of crop yield, but it should also be taken into account that the average weight of seeds and their number in a pod also significantly affect this indicator (Table 4).

Table 4. *Yield structure of winter rapeseed (averages for 2022-2023)*

Hybrid	Seeds, pcs		Seed Weight, g		
	per pod	per plant	pod	per plant	per 1,000 seeds
Dario	21.1	5,262.3	0.0785	19.55	3.72
Oriolus	18.8	4,126.6	0.0716	15.72	3.81
Blackstone	16.9	3,359.7	0.0624	12.41	3.69
Medium	18.9	4,205.2	0.0708	15.73	3.74
HIP	1.18	-	0.0063	-	0.265

Source: *created by the authors*

The average pod length ranged around 50.0 mm, which corresponds to the typical pod size of the hybrid, as indicated by the breeder. The number of seeds per pod ranged from 16.9 to 21.1. There was no significant difference in the average seed weight among the hybrids, which ranged from 3.69 to 3.81 g per 1,000 seeds. However, taking into account the number of pods per plant and the number of seeds per pod, there was a difference in the productivity of individual plants. For example, the Dario hybrid produced 19.55 g per plant, the Oriolus hybrid – 15.72 g per plant, and the Blackstone hybrid – 12.41 g per plant. Due to the biological characteristics of the hybrid, which determine the formation of the plant's morphological structure, the total seed mass differed significantly, with the difference between the highest and lowest values ranging from 24.3% to 57.5%.

As a result, it was established that the yield of winter rapeseed depended not only on the genetic potential of the hybrid but also on the meteorological conditions during the years of the study. A prolonged autumn vegetation period promoted the development of the root system and the formation of the leaf apparatus. During the winter period, there were no severely low temperatures that could have damaged the plants. The most challenging was the spring period, when ambient temperatures-initiated vegetation, but there was no possibility to conduct additional irrigation. The most favourable hydrothermal conditions for winter rapeseed occurred in the spring (April) and early summer (June) of 2023. Precipitation contributed to creating a comfortable microclimate near the ground surface, which positively affected the formation and functioning of the assimilation apparatus (BBCH growth stages: 3 – elongation of the main stem; 5 – pod formation). During this period, key processes in winter rapeseed plants were observed, such as stem growth, leaf formation, emergence of flower stalks, flowering, and the development of full pods. Overall, the proper and timely implementation of key cultivation practices for winter rapeseed, taking into account the region's climatic features, contributed to yields ranging from 2.52 to 5.41 t/ha (Table 5).

Table 5. *Yield of winter rapeseed hybrids depending on biological characteristics, t/ha*

Hybrid	Years of research			Deviation		Yph, t/ha	Rbp, %
	2022	2023	Average	t/ha	%		
Dario	4.37	5.41	4.89	+0.96	124.43	7.0	69.9
Oriolus	3.51	4.35	3.93	0.00	100.00	6.6	59.5
Blackstone	2.52	3.70	3.11	-0.82	79.13	5.5	56.5
Medium	3.47	4.49	3.98	+0.05	101.27	6.3	63.2
HIP	0.28	0.33					

Notes: *Yph – yield potential of the hybrid, t/ha; Rbp – ratio of the actual yield of the hybrid to its yield potential*
Source: *created by the authors*

As a result of the research, varying adaptive responses of winter rapeseed hybrids to high temperatures and relatively low air humidity during the summer period were identified. The Dario hybrid demonstrated the best realisation of its biogenetic potential. It showed the highest number of shoots of all branching orders – 15.3, the highest number of pods per plant – 249.4, and 21.1 seeds per pod. These conditions contributed to the highest yield, which averaged 4.89 t/ha over the two years of the study. The lowest comparative photometric indicators were recorded in the Blackstone hybrid, which in turn resulted in the lowest yield – 1.78 t/ha (or 63.4%) less than that of the Dario hybrid.

Taking into account the average yield potential of the studied hybrids, as indicated by the originators, and comparing it with the results of the research, it becomes evident that under the conditions of the Southern Steppe of Ukraine, they were able to realise, on average, 63.2% of their genetic potential. However, it should be noted that the winter rapeseed seeds used for the experiment were obtained from "DSV-Ukraine", a subsidiary of Deutsche Saatveredelung AG (DSV), based in Lippstadt, Germany. It can be assumed that the variability range of traits such as tolerance to high temperatures and low air humidity in the parental lines was insufficient for the resulting hybrids to fully realise their potential in this arid region.

DISCUSSION

Effective agricultural management in modern conditions largely depends on the identification and scientifically grounded direction of enterprise activities. A crucial aspect is the prioritisation of product realisation, including its export potential. Researchers M.I. Bakhmat & I.V. Sendetskyi (2020) noted that rapeseed accounts for approximately 10% of global oilseed production, ranking third in terms of cultivation volume. One of the tasks aimed at improving the organisational and economic indicators of the agricultural sector involves comprehensive measures to expand the production of oilseed crops, including rapeseed, which is highly profitable and promising.

O. Kulakova (2023) indicated that rapeseed production in European Union countries is projected at 20.2 million tons with a yield of 3.33 t/ha. The significant increase in global demand for rapeseed seeds is primarily associated with the substantial development of alternative bioenergy. I.V. Smirnova & V.M. Galaban (2024) noted that global rapeseed production in 2024/25 is forecasted by experts to exceed 88.34 million tons. The high demand for vegetable oils used for biofuels and lubricants significantly strengthens the crop's position in the international market, and the creation of modern high-yield hybrids provides a significant impetus for expanding its cultivation areas. S. Kyrychok (2022) emphasised that rapeseed is also an important forage crop, with green mass yields in winter intermediate crops reaching 34-36 t/ha, equivalent to 36-38 feed units. Additionally, rapeseed serves as a phytosanitary crop in crop rotations with a high concentration of cereal grains.

Ukraine possesses favourable soil and climatic conditions for obtaining stable yields of winter rapeseed across most of the Forest-Steppe, Western Polissia, and parts of the Northern Steppe, provided that technological aspects of production are adhered to. The expansion of rapeseed seed production in Ukraine directly depends on the crop's assortment. At the time of planning and establishing the experiment, the Catalogue of plant varieties suitable for distribution in Ukraine (2025) listed 129 varieties and hybrids of winter rapeseed, including 77 recommended for cultivation in the Steppe zone. By 2025, this number has increased to 378 winter rapeseed samples, with nearly half recommended for cultivation in the Steppe zone. The experiment involved winter rapeseed hybrids from the "DSV" breeding centre, which may be promising for cultivation under irrigation conditions.

According to research by A. Plotnitska *et al.* (2020), regardless of the direction of rapeseed breeding, special attention was paid to creating hybrids and varieties with increased potential productivity through the optimisation of the morphological structure of plant organs and their functioning. Varieties of different geographical origins differ in adaptive and productive characteristics. For instance, differences in plant overwintering ranged from 0.5-3.0%, carbohydrate accumulation in the root neck from 0.2-0.8%, resistance to downy mildew from 7.0-21.3%, alternaria from 15-34.2%, phoma from 6.1-11.0%, yield from 0.15-0.41 t/ha, 1,000-seed weight from 0.02-0.37 g, oil content by 2.0%, and erucic acid content by 0.2 μmol/g. Ultimately, hybrids and varieties should be characterised by high and stable yields over the years, high oil and protein content, drought and winter hardiness. Preference is given to early-maturing hybrids resistant to pod shattering, lodging, and diseases and pests, with broader ecological adaptability. For the southern region of Ukraine, requirements for adaptive hybrids include drought and winter hardiness (Markova *et al.*, 2025).

In this context, studying the features of morphological structure formation and productivity of new winter rapeseed hybrids under the conditions of the Southern Steppe of Ukraine is relevant. Winter rapeseed hybrids from the "DSV" producer are characterised by intensive root system development in the initial growth phases according to the BBCH scale and possess genetic resistance to pests. Their biological characteristics allow for the formation of a well-developed leaf apparatus and a deeply penetrating root system during the autumn period before the onset of unfavourable conditions, which ultimately contributes to good plant adaptation to extreme hydrothermal conditions occurring in December-February (Muntyan *et al.*, 2024). The winter hardiness of the hybrids studied in the experiment was rated at 9 out of 10 points. Balanced development of the above-ground part of the plant and a well-developed root system also determines sufficient drought resistance during the summer period of active vegetation (9 out of 10 points). Already in the autumn period, during phase 2 – development of lateral shoots (20 – lateral shoots absent) according to the BBCH scale of winter rapeseed development, prerequisites for the development of lateral shoots in the axils of true leaves are laid, and in phases 21-29, lateral shoots begin to form. In phase 3 – elongation of the main stem (30 – beginning of stem growth), the 0-order branching stem begins to grow (according to the BBCH scale – main stem).

In comparative tables of rapeseed hybrids, indicating their features, primarily agronomic and morphological characteristics, disease and stress resistance, important indicators include average yield over years of testing and potential yield. For the group of VNIS hybrids (Blackstone, Grim, Parker, Redstone, Trump, Hulk, etc.), the potential yield is 7.0-7.2 t/ha, yield over years of testing – 4.7-5.2 t/ha, with the realisation of biogenetic potential reaching 65.3-73.9%. Over the years of testing, the yield of hybrids presented in the studies ranged from 2.52-5.41 t/ha, and the realisation of hybrid yield potential – 56.5-69.9%. In the southern region, under the conditions of adhering to the main elements of the technological process, average yield indicators and realisation of the biogenetic potential of hybrids were at the level of indicators presented in reference literature. High rapeseed productivity, according to M. Parkhomets *et al*. (2023), is associated with the creation of regional zones of concentrated winter form cultivation, allowing for the effective use of soil-climatic and material-technical resources and effective agrotechnical measures.

According to research by O. Klyachenko (2021), the realisation of the biomorphological potential of winter rapeseed hybrids and varieties is based on creating a balanced morphological structure of plants. It should be noted that the natural accumulation of reproductive organs on shoots of different branching orders, considering the photosynthetic apparatus, has a certain pattern. As a rule, winter rapeseed develops a sufficiently developed single shoot – the 0-order branching shoot (Zabarniy & Zabarna, 2024). As records showed, 25.3-31.6 pods formed in its upper part. In the axils of leaves on the 0-order branching shoot, 7.1-10.4 first-order branching shoots formed, on which 158.0-194.5 pods were counted, averaging 19.9 pods per shoot. On first-order branching shoots, 1.7-3.9 second-order branching shoots formed, with 15.5-26.2 pods on them. Thus, the distribution of pods depending on the branching order of shoots follows the trend: 0-order – 12.8%, 1^{st} order – 77.7%, 2^{nd} order – 9.5%. The number of seeds, their weight, and yield distribution by branching character generally follow the same pattern as the pod distribution on the plant.

The conditions of plant cultivation significantly influenced the formation of generative organs. In the conditions of the Western Forest-Steppe of Ukraine, Ukrainian selection rapeseed varieties (Pegas, Solo, Smaragd, Stilutsa) performed well, with seed yields of 3.94-4.03 t/ha. Plants had 115-119 pods, including 59-60 on 0-order branching shoots. V.M. Sendetskyi *et al*. (2023) indicate that in plots without fertiliser application, the number of pods was 89-95 pcs/m², and with the application of $N_{210}P_{135}K_{165}$ – 99-105 pcs/m². V.M. Bezkorovaynyi & V.V. Moisienko (2024b) noted that with a row spacing of 30 cm, modern winter rapeseed hybrids can form an average of 419.1 to 444.0 pods per plant. The formation of the morphological structure of winter rapeseed in the conditions of the Western Forest-Steppe and the Southern Steppe has significant differences because, in the Southern Steppe, the cultivation technology of winter rapeseed must utilise moisture-conserving elements of technology, which significantly reduces the risk of its production. To model the optimal distribution of a plant's productive organs, it is necessary to reasonably generalise the following indicators: determine the optimal number of first-order branches per plant and the distribution of pods on them; justify the feasibility of stimulating the growth of second-order branches and placing pods on them (Nikochuk & Mykolaichuk, 2025).

Research has shown that only 40-60% of plants form yield on second-order branches, and the average number of pods per such branch ranges from 6.7 to 11.1. By the time of rapeseed harvest, the optimal plant parameters that promote the realisation of genetic potential and determine yield can be regulated through technological process components, including plant spacing, the use of growth regulators, scientifically justified fertiliser application rates, and improvement of the water-air regime in the crop biocenosis.

CONCLUSIONS

The winter rapeseed seeds obtained for the study showed high sowing and varietal quality indicators and met the standards required for first-class seed. The weather conditions of the Southern Steppe of Ukraine are generally suitable for growing winter rapeseed. However, there was an insufficient amount of natural precipitation during the plant's vegetation period, especially in the early stages of growth and development, as well as during flowering and fruit-setting phases. To improve hydrothermal conditions during critical vegetation periods, additional irrigation is necessary, taking into account soil moisture and the physiological state of the plants.

A biological characteristic of the crop allows for the development of first- and second-order lateral shoots during the spring period. The total number of shoots developing on a plant, depending on the hybrid, ranges from 9.8 to 12.3, with first-order branches comprising the largest share of the structure (68.0-72.4%). The winter rapeseed hybrids had a sufficiently developed reproductive component, enabling the formation of 198.8-249.4 pods per plant. The majority of pods were located on the first-order shoots (75.8-79.5% of the total), which largely determined the yield. The average seed weight (per 1,000 seeds) among the studied hybrids varied slightly, ranging from 3.69 to 3.81 g. Yield was determined by the weather conditions during the experiment and the biological characteristics of the hybrid. Under the conditions of the southern region, the realisation of the biogenetic potential of the winter rapeseed hybrids was at the level of 56.5-69.5% of the potential yield, amounting to 2.52-5.41 t/ha.

The highest yield during the experiment was observed in the Dario hybrid. The biomorphological characteristics of the plants that determined yield were as follows: total number of shoots per plant – 15.3, including 10.4 first-order shoots; total number of pods per plant – 249.4, including 194.5 on first-order shoots; average weight of 1,000 seeds – 3.72 g; average yield over the experiment – 4.37-5.41 t/ha; realisation of biogenetic potential – 62.4-77.3%. The lowest yield during the experiment was observed in the Blackstone hybrid. The plant biomorphological indicators that determined productivity were as follows: total number of shoots per plant – 9.8, including 7.1 first-order shoots; total number of pods per plant – 198.8, including 58.0 on first-order shoots; average weight of 1,000 seeds – 3.69 g; yield over the experiment – 2.52-3.1 t/ha; realisation of biogenetic potential – 45.8-67.3%.

Targeted efforts aimed at forming a balanced ratio between vegetative and reproductive plant organs (total number of shoots per plant, number of 0-1-2 order shoots, number of pods per shoot, their optimal combination in the shoot/pod ratio, seed weight per pod) through the implementation of adaptive technological elements-such as the use of growth regulators and the application of micro- and macroelements during the rosette leaf and lateral shoot development stages (BBCH growth stages 20-30) – require further research.

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CONFLICT OF INTEREST

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Продуктивність ріпаку озимого залежно від морфоструктури рослин в умовах Степу України

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Анотація. Метою досліджень було визначення показників морфоструктури продуктивних органів ріпаку озимого, які впливають на врожайність і встановлення на їх основі стратегічного напрямку формування перспективного сортименту для вирощування культури в умовах Південного Степу України. На прикладі гібридів ріпаку Даріо, Оріолус, Блекстоун – (ВНІС) представлена порівняльна морфоструктура вегетативних і генеративних органів рослин і її вплив на урожайність. Відмічалося, що чистота насіння, яке використовували в дослідженні, склала 100,0 %, лабораторна схожість – 91,6-94,0 %. Загальне число пагонів на період збирання урожаю визначалася значною мірою біологічними властивостями гібриду і коливалась в межах 9,8-15,3 штук/рослину. Обґрунтовано, що продуктивність посівів визначалась передусім наявністю стручків на пагонах 1-го порядку галуження, що складало в структурі врожаю – 75,7-78,5 % від їх загальної кількості залежно від біологічних особливостей гібридів. Кількість стручків, розміщених на пагонах 0-го і 2-го порядків галуження була незначною і складала 12,8 % і 9,5 % відповідно. Середня маса 1 000 насінин між досліджуваними гібридами відрізнялась не суттєво і коливалась в інтервалі 3,69-3,81 г. Різниця у величинах урожайності між гібридами визначалася за комплексними показниками продуктивності, зокрема, загальною кількістю стручків на рослині і кількістю насінин в стручку. Найбільша кількість стручків була у гібрида Даріо – 249,4 шт./рослині, найменша – у гібрида Блекстоун – 198,8 шт./рослині. Оптимальна морфоструктура рослин виявилась у гібрида Даріо, що сприяла не тільки отриманню найвищого урожаю (4,89 т/га), але й реалізації в найвищому ступені біогенетичного потенціалу гібриду (69,9 %). Нижчі порівняльні показники були виявлені у гібрида Блекстоун, урожайність і реалізація біогенетичного потенціалу склали відповідно 3,11 т/га (56,6 %)

Ключові слова: гібрид ріпаку; морфоструктура рослин; галуження; стручок; насіння; урожайність