Research **20**(X), xxx–ccc, 2022
https://doi.org/10.15159/AR.22.035

The influence of agroecological and agrotechnological factors on the generative development of oilseed radish (*Raphanus sativus* var. oleifera Metzg.)

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Received: April 1st, 2022; Accepted: May 28th, 2022; Published: June 22nd, 2022

Abstract. During the eight-year research period, we determined the peculiarities and regularities of morphological (length and diameter) and anatomical (stem thickness) features of oilseed radish pods considering their location within the generative part of plants for different types of spatial structure of the inflorescence generated in agrocenosises of different densities. We carried out the analysis and statistical grouping of morphological features of oil radish pod in the full range of possible technological options of pre-sowing construction of its agrocenosises, as well as within the selected three zones (tiers) of inflorescence by the nature of variation and variability of morphoparameters pod, namely, lower, middle and upper. We described in detail the stages of pod formation (microstages BBCH 69-87) considering features of its linear and radial growth, peculiarities of formation of general internal anatomical structure with analysis of mathematical and statistical regularities of changes in these parameters in accordance as per order of its placement within an inflorescence (separately main axis and system of lateral branches). We determined the optimum technological intervals for the construction of oilseed radish agrocenosises, which ensure the combination of appropriate levels of morphometry formation of its fruit elements with the predicted level of reproductive effort and seed productivity. We made a general assessment of the peculiarities of formation of pod technological effectiveness in terms of ease of threshing and possible losses of seeds depending on the complex of factors under study.

Keywords: inflorescence, layering, morphological characteristics, *Raphanus sativus* var. *oleifera* Metzg., pod, variability, variation.

INTRODUCTION

Productive flowering, fruit formation and ripening for different plant species is a common biological basis for successful tactics of reproduction, seed dissemination and dominance in certain areas (Forlani et al., 2019). Aspects of variability of the generative part of plants are crucial in assessing the formation and realization of seed potential of plants (Ballester & Ferrendiz, 2017). The peculiarities of the formation of such variability are determined by many factors depending on genetically determined values, taking into account the species specificity of plant response to abiotic environmental parameters, especially the ratio of temperature and atmospheric humidity from the beginning to the end of flowering and seed maturation (Parvaiz, 2017; Van der Knaap & Ostergaard, 2018; Dong & Østergaard, 2019; Chai et al., 2020; Chen et al., 2021; Ahmad et al., 2021).

For cruciferous plant species, morphological variability of pods is decisive for predicting yield levels, ensuring crop planning with minimal losses and ensuring the high technological quality of harvested seeds (Gulden et al., 2017; Nikolov, 2019; Shafighi et al., 2020). In general, the pronounced variability of morphometry of cruciferous pods is due to a number of factors. The main ones are related to the growth processes of the inflorescence itself, which is usually characterized by an insert type of growth with the formation of flowers from its base to the apex (Qing et al., 2021). The process of flower formation in cruciferous species is quite stretched in time. Due to this, in the generative part of the plants there are both fully formed pods and flowers at the stage of flowering (Ågren et al., 2017; Tsytsiura, 2019). This ultimately determines the variability of future morphometry of pods (on such features as pod length, pod diameter, thickness of pod walls, intensity of its pubescence, thickness of intrafertile histological elements) in the spatial structure of inflorescences with differentiation of pods in the direction from inflorescence base to its apex (Łangowski et al., 2016; Yang et al., 2016a, 2016b, 2017; Dong et al., 2018; He et al., 2020; Li et al., 2019, 2020; Sun et al., 2021).

The spatial structure of both the inflorescence and the subsequent placement of pods is complicated by the presence of lateral branches of different order (Lu et al., 2017; Strelin & Aizen, 2018; Dogra & Dani, 2019; Tsytsiura, 2019; Li et al., 2020). Changes in the spatial structure of the reproductive part of both cruciferous and other plant species are based on the interaction of genotypic characteristics, the level of modifying variability (ecological, matrix), environmental factors and agrotechnological parameters of agrocenosis and fertilization (Inger et al., 2019; Li et al., 2021; Gianella et al., 2021). Thus, the level of adaptability of the applied agro-technological parameters of pre-sowing construction of agrocenosis can potentially be assessed by the nature of the architecture of the reproductive part of plants. It should be noted that for many groups of crops, aspects of these factors are insufficiently studied (Labraa et al., 2017; Rauf & Rahim, 2018; Kayaçetin et al., 2018; Tsytsiura, 2021).

On the other hand, studies conducted on spring and winter rape, white mustard and a number of other cruciferous crops have shown that the assessment of generative part formation is one of the basic requirements for predictive modeling of seed productivity (Liao et al., 2009; Neuffer & Paetsch, 2013; Salisbury et al., 2017). It is important to form the initial system of indicators that clearly regulate the sequence of inflorescence formation and features of its morphometry depending on agrotechnological options for constructing agrocenosis (Classen-Bockhoff & Bull-Herenu, 2013; Walker et al., 2021). Insufficient study of the peculiarities of the formation of the spatial structure of the inflorescence, the dynamics of pod development and the impact of these factors on the structure of individual biological seed productivity of plants (Harder and Prusinkiewicz, 2013; Matar et al., 2021). According to Menendez et al. (2019) this approach is the main one in view of current trends in assessing the effectiveness of various technological methods and allows to separate the formation of vegetative mass and seeds in a staged format with the identification of the main factors influencing it. For cruciferous crops, the analysis of the ratio of vegetative and reproductive parts is a basic aspect of the analysis of yield and adaptability (Wang et al., 2018).

It should be noted that the assessment of the peculiarities of inflorescence formation will allow to detail the processes of seed loss during its maturation and harvesting (Raboanatahiry et al., 2021). In particular, for spring and winter rape, these issues are included in the program of breeding research and according to Shahzadi et al. (2015) need to re-evaluate and apply new approaches. Given that the pods of oilseed radish are undiscovered with certain features of the anatomy (Tsytsiura, 2020, 2021) it would be important to study the dynamics of anatomical changes in the its formation. Such studies will allow to apply the identified features in the selection improvement of traditional cruciferous crops, the fruits of which are revealed during the ripening of seeds.

It is established that the problems of successful mechanized threshing of oilseed radish due to the anatomical features of its pod limit the prevalence of this culture from the standpoint of successful seed production (Chammoun, 2009). In view of this, the study of biological components of the formation of oilseed radish pods on the background of the full range of applied agro-technological parameters of pre-sowing design of its agrocenoses will identify specific solutions to this pressing problem.

Most research in this area is related to cruciferous crops (Weberling, 1992; Alvarez-Buylla et al., 2010; Penin & Logacheva, 2011; Harder & Prusinkiewicz, 2013; Brunel-Muguet et al., 2015; Wang et al., 2018; Siles et al., 2021) cover the assessment of the peculiarities of inflorescence formation, reproductive effort and don’t cover the full cycle from the stage of inflorescence formation to pods formation in the spatial structure of its branches. Given this fact, the combination of a comprehensive study of the impact of agroecological factors (in a complex combination of agrotechnological parameters of agrocenosis and hydrothermal regimes) on the stages, dynamism and spatial structure of cruciferous elements from flowering to pod ripening is an important task. This area of research has all the hallmarks of innovation and scientific novelty and will be useful for modern agrobiological and breeding practice of cruciferous crops. The results obtained due to such an integrated approach on the example of oilseed radish will allow to use them as indicators for optimizing the technological formation of cruciferous agrocenoses.

MATERIALS AND METHODS

The research was conducted during 2013–2020 on the experimental field of the Vinnytsia National Agrarian University (49°11′ N, 28°22′ E) on dark gray forest soils (Luvic Greyic Phaeozem soils (WRB, 2015)). During the oilseed radish growing season of April-September (178 days). Height above sea level: 325 m. The general agrochemical characteristics of this soil type are as follows: humus content: 2.02–3.20%, lightly hydrolyzed nitrogen 67–92, mobile phosphorus 149–220, exchangeable potassium 92–126 mg kg^{-1} of soil at pHкcl 5.5–6.0. Technological parameters for the formation of oilseed radish agrocenosises were carried out in the interval of recommended variants in terms of common row (row spacing of 15 cm) and wide-row (row spacing of 30 cm) sowing methods (Table 1).

The study was conducted on basic area-specific oilseed radish genotypes, namely ‘Zhuravka’, ‘Lybid’ and ‘Raiduha’. Given the similarity of the identified regularities and peculiarities, the materials presented in this paper relate to the ‘Zhuravka’ variety with relevant practical conclusions regarding the general species of oilseed radish (Raphanus sativus var. oleifera Pers.). The sowing period for all research variants was in the range of April 8–12.

The analysis of pod morphology was carried out both within the generalized typical zones of the inflorescence and in its dominant middle zone, considering such features as pod length (l, cm), diameter (d, mm), wall thickness (hw, mm). The specified indicators were considered on 10 typical plants in incompatible replications for each technological variant of agrocenosis construction. The plant typicality and determination of the inflorescence zones were carried out according to the systems of studying the formation of the tiered spatial structure of plants according to the basic principles of phytocenology for technologically formed artificial agrocenoses (Ramensky, 1971; Rabotnov, 1978), and according to the methods of similar estimations applied to white mustard (Kumar et al., 1996) and spring rape (Khmelyanchyshyn, 2005). We assessed the variation in the morphological parameters of the fruit by sampling 125 pods for each repetition in the section of the selected inflorescence zones (a total sample of 500 pods from each inflorescence zone). The total number of replicates of each variant is 4. The plant analysis involved evaluating a group of 5 typical plants according to row length stochastically by plot width with a shift in row horizontally from the beginning of flowering of the plants ((Biologische Bundesanstalt, Bundessortenamt and Chemical industry (BBCH) 62 (Meier, 2001)) to the phase when all pods have reached the variety and typic size (BBCH 87). For dynamic observation of the intensity of linear and lateral growth of the pod, we marked the indicator plants using coloured markers with the corresponding numbers.

Table 1. The range of acceptable common options for the formation of oilseed radish agrocenosis at the location of the study

Planting method and seeding rates (million germinable seeds·ha^{-1})		Fertilization (of the active substance), kg·ha^{-1}
Row method (15 cm)	Wide-row method (30 cm)	
1.0	0.5	$N_0P_0K_0$
2.0	1.0	$N_{30}P_{30}K_{30}$
3.0	1.5	$N_{60}P_{60}K_{60}$
4.0	2.0	$N_{90}P_{90}K_{90}$

To determine the morphometric characteristics of the pod a Topex 31C625 digital caliper (± 0.01 mm) and a Digital Caliper electronic micrometer (± 0.01 mm) was used. We used the USB microscopy method for microscopic examination of the pod slices (Sigeta MCMOS 5100 5.1 MP USB 2.0 (x10 and x40 optical zoom formats) and Ootdty DM-1600, 2 Megapixel + Image J software package v1.52. Photo images were taken using Canon EOS 750D Kit with Canon EF 100mm f/2.8L USM and Canon MP-E 65 mm f/2.8 1-5x Macro.

The general research methodology, the recording of the macrostages of the phenological phases of the oilseed radish fruiting period and other related observations and records were conducted in accordance with the basic research recommendations for cruciferous crops (Sayko, 2011) and the methodological descriptive recommendations of the classification ranking tables (Test Guidelines…, 2017) using experimental statistical approaches (Dunstone & Yager, 2009) in the format of four-factor dispersion analysis (Multivariate Analysis of Variance (MANOVA) and pack of statistical programs Statistica 10, Exel 2013. We performed simulations with the selection of appropriate functional dependencies using the CurveExpert Professional 2.7.3 software package.

The climate of the region is moderately continental (Dfb according to the Köppen-Geiger climate classification (Pivoshenko, 1997). During the study period, the maximum and minimum average monthly temperature were 18.3 °C in July and 15.8 °C in May. Mean annual relative humidity was 77% and mean annual precipitation was 480–596 mm.

The hydrothermal parameters of the oilseed radish vegetation period varied, having formed certain typological features of the research years (Fig. 1, Table 2).

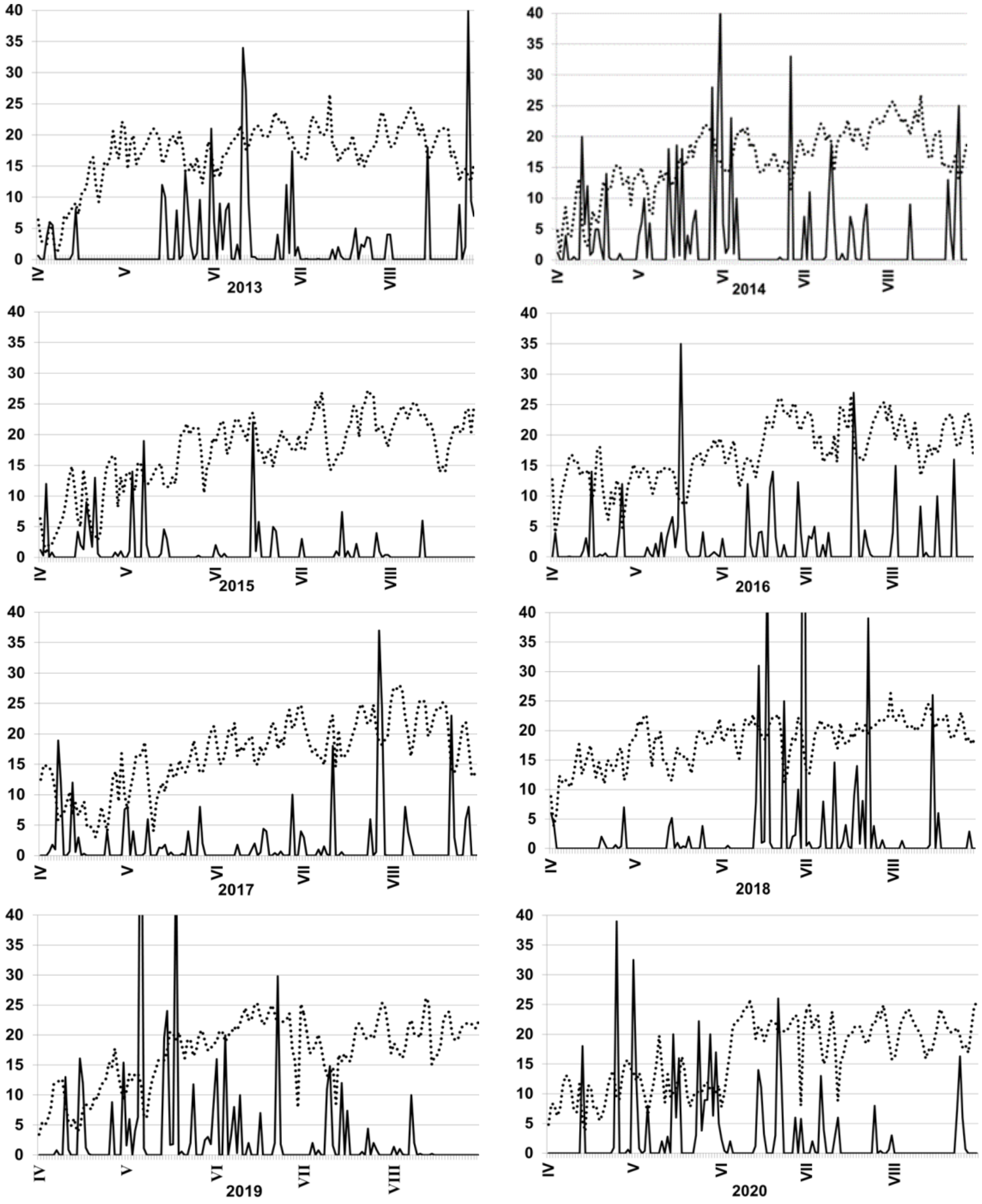


Figure 1. The hydrothermal conditions for April-August (2013–2020) (dashed line – average daily temperature, °C, solid line – rainfall, mm).

The conditions of 2013 and especially of 2014 can be referred to as the most optimal for the growth processes of the oilseed radish due to the combination of slow rates of increase in average daily temperatures and equal precipitation from the end of May to mid-June. This corresponds phenologically to the active vegetation in the study area, and the rare vegetation coincides with the interphase of the stem-flowering phenological period (BBCH 30-65). For the period of research, we must classify the conditions of 2015 and 2018 as stressful for the physiological and growth processes of oilseed radish plants according to the ratio of precipitation equality and the nature of the average daily temperature curve. For instance, the precipitation distribution in 2015 was uneven with the total absence during the period of the second decade of May - the second decade of June due to the intense and rapid increase of average daily temperatures during the same period at the high amplitude of values. This created a double effect of the overall stress of the environmental factor in the inter-phase start of budding-flowering (BBCH 38-64) with respect to the oilseed radish plants and made it possible to evaluate the studied indicators in the environmental-trait system effectively.

Table 2. Monthly average hydrothermal coefficient* over the growing season of oilseed radish, 2013–2020

Year of research	Months					Average value for the period of pod formation**	Average for the years of vegetation
	V	VI	VII	VIII	IX		
2013	1.305	2.202	0.377	1.047	3.441	1.614	1.527
2014	2.783	1.078	1.137	0.750	0.736	1.618	1.269
2015	0.719	0.613	0.230	0.061	0.684	0.535	0.430
2016	1.227	0.893	0.682	0.486	0.063	0.987	0.663
2017	0.645	0.349	0.806	0.563	1.983	0.562	0.824
2018	0.258	3.124	1.349	0.349	0.680	2.628	1.179
2019	4.710	1.555	1.003	0.235	0.945	1.569	1.690
2020	5.489	1.474	0.649	0.474	1.208	1.331	1.859

* – $HTC = \frac{\sum R}{0.1 \times \sum t_{>10}}$ (Selyaninov, 1928), where the amount of rainfall (ΣR) in mm over a period with temperatures above 10 °C, the sum of effective temperatures ($\Sigma t > 10$) over the same period, decreased by a factor of 10. Ranking of values HTC (Selyaninov, 1928; Evarte-Bundere & Evarts-Bunders, 2012): HTC > 1.6 – excessive humidity, HTC 1.3–1.6 – humid conditions, HTC 1.0–1.3 – slightly arid conditions, HTC 0.7–1.0 – arid conditions, HTC 0.4–0.7 – very arid conditions. ** – Period of pod formation (perennial variable interval): III decade of May – II decade of July.

We observed a prolonged atmospheric and soil drought with a slight humidity until the second decade of June for the conditions of 2018 against the background of low average daily temperatures, which, unlike the conditions of 2015, affected the magnitude of the architecture of oil radish plants from the stage of rosette formation and its further stalking (BBCH 19-38). For these reasons, the stressful year 2018 is the most illustrative in the assessment of stress. We must attribute the 2016 and 2017 years of research to the intermediate ones by hydrothermal parameters in the six-year study cycle with a similar dynamic regime of average daily temperatures and uneven atmospheric humidity. In this case, the conditions of 2016 are close to 2013–2014, and the conditions of 2017 are similar to those of 2015. The 2019 growing season was characterised by a cool period from sowing to the rosette phase against a background of intense atmospheric moisture over the period from May to June, which was significantly higher than the multi-year average. An intense rise in temperatures was recorded from mid-June with steady atmospheric moisture until mid-July. The 2020 hydrothermal conditions were marked by the temperature conditions as abnormally low between April and May, in line with the biological optimum of oilseed radish growth and development. The amplitude of temperature fluctuations for this year of research was one of the largest.

As a result, the increase in the overall favourable hydrothermal regimes of oilseed radish vegetation in the direction of reducing the weather risks of impact on the reproductive part of the plants should be placed in the following order: 2018–2015–2017–2016–2013–2020–2019–2014.

RESULTS AND DISCUSSION

Oilseed radish is characterized by a certain response in plant morphogenesis to changes in such technological parameters as the density of plants and the width of row spacing against the background of various options of using mineral fertilizers (Tsytsiura, 2020). This reaction is determined by a certain morphotypes of oilseed radish plants in terms of the spatial structure of their inflorescence (Figs 2–3).

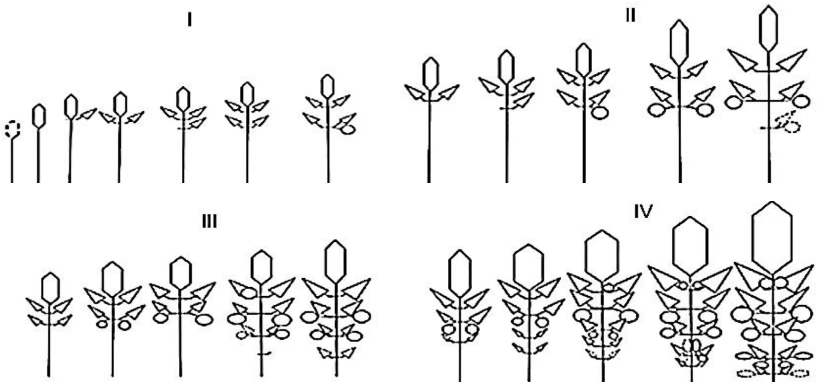


Figure 2. Types of spatial structure of the inflorescence of oilseed radish plants of the 'Zhuravka' variety of different tiers of agrocenosis at different variants of its technological construction (I – at the sowing rate of 4.0 million pcs. ha^{-1} of germinable seeds on a nonfertilized ground; II – at the sowing rate of 4.0 million pcs. ha^{-1} of germinable seeds with fertilization rate of 90 kg N ha^{-1}, 90 kg P ha^{-1}, and 90 kg K ha^{-1}; III – at the sowing rate of 0.5 million pcs. ha^{-1} of germinable seeds on a nonfertilized rate; IV – at the sowing rate of 0.5 million pcs. ha^{-1} of germinable seeds with fertilization rate of 90 kg N ha^{-1}, 90 kg P ha^{-1}, and 90 kg K ha^{-1} based on the results of multi-year assessments for the 2013–2020 period (conventional symbols: ⬭ – main stem inflorescence; ▷ – inflorescences of lateral branches of the first tier; ⬡ – inflorescences of branches of the second tier; ○ – inflorescences of branches of the second tier).

According to some research (Rabotnov, 1978; Al-Doori & Hasan, 2010; Bhushan et al., 2013; Chang et al., 2020) such changes in the architectonics of the reproductive part indicate an appropriate level of compensatory capacity of plants and an appropriate level of adaptation to growing conditions. The studies found (Yang et al., 2016b; Labraa et al., 2017; Kirkegaard et al., 2018; Han et al., 2021), that according to the character of changes in the inflorescence structure in terms of potential productivity (number of flowers, number of inflorescence branches, mass fraction of inflorescence in relation to the weight of the above-ground plant part), we can draw conclusions about the compensatory adactive biological potential of plants. Studies on the variability of the number of lateral branches of the inflorescence with changes in seeding rate and nutrition area found the value of this indicator for winter and spring rape in the range from 2 to 15 branches (Gomez-Campo, 1999; Koenig et al., 2011; Brunel-Muguet et al., 2015; Pinet et al., 2015; Li et al., 2016; Halevy, 2019; Haliloglu & Vedat, 2019; Adhikari et al., 2021) and for white mustard from 5 to 17 branches (Chaniyara et al., 2002; Zając et al., 2011; Zhuikov, 2014; Jat et al., 2017; Rauf & Rahim, 2018). According to these values, the potential for branching of oilseed radish inflorescences in the comparison of options 4.0 and 0.5 million pcs. ha^{-1} of germinable seeds in the range from 1 to 21 branches indicated a higher level of its compensatory response than in other traditional cruciferous crops. Levels of lateral branching of inflorescences for limiting technological variants of sowing and fertilizer rates had significant differences (Fig. 2). It was noted over a long period of study of 1–5 lateral branches for the variant of 4.0 million pcs. ha^{-1} of germinable seeds without fertilizers and 9–21 for the variant of 0.5 million pcs. ha^{-1} of germinable seeds with fertilization rate of of 90 kg N ha^{-1}, and 90 kg K ha^{-1}. Supplementary mineral nutrition ensures quantitative optimisation of the reproductive organs of oilseed radish plants especially as regards both the total number of branches and indicators such as their length, the number of flowers on each branch, etc.

At the same time, we determined the sequence of quantitative increase in the general indicators of development of the reproductive part of oilseed radish plants when decreasing the seeding rate, increasing the area of plant nutrition, and optimizing their mineral nutrition (Fig. 3, Table 3). We found that with a high level of variation in the number of inflorescence branches within the studied technological variants, the increasing trend is stable with optimization of mineral nutrition and increase in nutrition area. So, for the variant of maximum density of 4.0 million pcs. ha^{-1} of germinable seeds the interval range of the indicator was 1.0–8.8 of lateral branches, and for the variant of 0.5 million pcs. ha^{-1} of germinable seeds it was 5.5–20.5.

Figure 3. Morphotype of oilseed radish plants of the 'Zhuravka' variety with fertilization rate of 90 kg N ha^{-1}, 90 kg P ha^{-1}, and 90 kg K ha^{-1} (from left to the right the first three positions: 0.5 million pcs. ha^{-1} of germinable seeds (wide-row sowing); the next three positions – 4.0 million pcs. ha^{-1} of germinable seeds), 2020.

Table 3. Summary morphological individual parameters of oilseed radish pods for the middle zone of the inflorescence at the yelow pod phase (BBCH 79-81) depending on the technological variation of agrocenosis construction, 2013–2020

Options of the experiment	Fertilizer	Average for 3 varieties (‘Zhuravka’, ‘Raiduha’ and ‘Lybid’)									
		Range of				Average values			V_R*		
		Inflores-cence branches (ib)	Length of the pod (l), cm	Diameter of the pod (d), mm	Thickness of walls’ pod (hw), mm	l, cm	d, mm	hw, mm	l	d	hw
4.0 million, row	$N_0P_0K_0$	1.0–6.3	2.17–6.09	4.14–9.06	0.33–1.42	4.36	6.78	1.03	0.90	0.73	1.06
	$N_{30}P_{30}K_{30}$	1.5–7.5	2.35–6.84	4.26–9.62	0.45–1.64	4.96	7.24	1.08	0.91	0.74	1.10
	$N_{60}P_{60}K_{60}$	2.1–8.3	2.62–7.02	4.37–9.79	0.49–1.72	4.91	7.21	1.1	0.90	0.75	1.12
	$N_{90}P_{90}K_{90}$	2.8–8.8	2.26–6.94	3.95–9.84	0.41–1.78	4.85	7.18	0.98	0.96	0.82	1.40
3.0 million, row	$N_0P_0K_0$	1.5–7.1	3.08–6.22	4.19–9.03	0.42–1.55	4.72	7.31	0.98	0.67	0.66	1.15
	$N_{30}P_{30}K_{30}$	1.8–8.1	3.24–6.96	4.29–9.78	0.45–1.67	5.32	7.92	1.21	0.70	0.69	1.01
	$N_{60}P_{60}K_{60}$	2.5–8.9	3.51–7.15	4.45–9.87	0.49–1.85	5.26	7.84	1.18	0.69	0.69	1.15
	$N_{90}P_{90}K_{90}$	2.8–9.4	3.36–7.21	4.29–9.75	0.40–1.80	5.26	7.79	1.09	0.73	0.7	1.28
2.0 million, row	$N_0P_0K_0$	2.2–8.4	3.41–6.48	4.26–9.31	0.45–1.41	4.95	8.09	1.02	0.62	0.62	0.94
	$N_{30}P_{30}K_{30}$	2.7–9.2	3.54–7.23	4.39–10.04	0.52–1.77	5.59	8.76	1.26	0.66	0.64	0.99
	$N_{60}P_{60}K_{60}$	3.2–10.5	3.62–7.35	4.48–10.26	0.58–1.95	5.65	8.91	1.22	0.66	0.65	1.12
	$N_{90}P_{90}K_{90}$	3.5–11.1	3.58–7.25	4.41–10.08	0.55–1.82	5.61	8.82	1.17	0.65	0.64	1.09
1.0 million, row	$N_0P_0K_0$	2.9–11.7	3.68–7.12	4.39–9.34	0.58–1.51	5.22	8.51	1.34	0.66	0.58	0.69
	$N_{30}P_{30}K_{30}$	3.5–13.9	3.79–7.81	4.51–10.26	0.65–1.94	5.78	8.99	1.44	0.70	0.64	0.90
	$N_{60}P_{60}K_{60}$	3.9–14.4	3.88–7.94	4.67–10.34	0.69–2.06	5.87	9.08	1.56	0.69	0.62	0.88
	$N_{90}P_{90}K_{90}$	4.5–17.3	3.91–8.05	4.68–10.47	0.71–2.13	6.02	9.32	1.62	0.69	0.62	0.88
2.0 million, wide-row	$N_0P_0K_0$	2.1–7.5	3.16–6.88	4.35–9.21	0.44–1.32	5.11	9.12	1.31	0.73	0.53	0.67
	$N_{30}P_{30}K_{30}$	2.6–8.4	3.21–7.44	4.49–9.96	0.56–1.64	5.64	9.64	1.35	0.75	0.57	0.80
	$N_{60}P_{60}K_{60}$	3.2–9.6	3.36–7.59	4.55–10.08	0.62–1.75	5.78	9.74	1.47	0.73	0.57	0.77
	$N_{90}P_{90}K_{90}$	3.6–10.3	3.39–7.64	4.59–10.14	0.59–1.79	5.81	9.72	1.58	0.73	0.57	0.76
1.5 million, wide-row	$N_0P_0K_0$	2.8–8.4	3.74–7.25	4.49–9.38	0.52–1.25	5.24	9.47	1.44	0.67	0.52	0.51
	$N_{30}P_{30}K_{30}$	3.2–9.2	3.92–8.22	4.61–10.59	0.62–1.71	5.97	9.99	1.58	0.72	0.6	0.69
	$N_{60}P_{60}K_{60}$	3.7–11.1	4.15–8.41	4.72–10.65	0.69–1.79	6.09	10.16	1.69	0.70	0.58	0.65
	$N_{90}P_{90}K_{90}$	4.2–12.4	4.25–8.57	4.84–10.72	0.71–1.82	6.12	10.28	1.78	0.71	0.57	0.62

Table 3 (continued)

1.0 million, wide-row	$N_0P_0K_0$	4.4–10.5	3.11–7.55	4.14–9.68	0.59–1.57	5.54	10.05	1.59	0.80	0.55	0.62
	$N_{30}P_{30}K_{30}$	4.8–11.3	3.23–8.91	4.27–10.92	0.69–1.86	6.08	10.51	1.77	0.93	0.63	0.66
	$N_{60}P_{60}K_{60}$	5.2–13.6	3.42–9.17	4.34–11.24	0.78–2.03	6.12	10.64	1.87	0.94	0.65	0.67
	$N_{90}P_{90}K_{90}$	6.1–15.7	3.54–9.27	4.51–11.39	0.75–2.08	6.26	10.76	1.94	0.92	0.64	0.68
0.5 million, wide-row	$N_0P_0K_0$	4.7–14.2	3.45–9.08	5.11–11.87	0.71–2.14	6.08	10.87	1.83	0.93	0.62	0.78
	$N_{30}P_{30}K_{30}$	5.5–15.1	3.14–9.32	5.13–12.69	0.78–2.33	6.59	11.41	1.95	0.94	0.66	0.79
	$N_{60}P_{60}K_{60}$	6.7–17.3	3.19–9.84	5.16–12.89	0.79–2.44	6.91	11.44	2.04	0.96	0.68	0.81
	$N_{90}P_{90}K_{90}$	8.6–20.5	3.23–10.07	5.24–13.07	0.81–2.52	6.98	11.85	2.11	0.97	0.68	0.86

LSD$_{05}$	ib	l	d	hw	The share of influence				
						ib	l	d	hw
LSD$_{05}$ factor A (year)	0.11	0.04	0.05	0.006	A	11.81	32.32	26.40	22.69
LSD$_{05}$ factor B (sowing method)	0.05	0.02	0.02	0.003	B	16.27	13.17	26.01	29.13
LSD$_{05}$ factor C (sowing rate)	0.08	0.03	0.03	0.004	C	38.41	29.12	26.72	31.81
LSD$_{05}$ factor D (fertilizer)	0.08	0.03	0.03	0.004	D	26.41	12.15	10.50	7.86
LSD$_{05}$ interaction AB	0.15	0.06	0.07	0.009	AB	0.38	1.90	1.52	1.14
LSD$_{05}$ interaction AC	0.21	0.09	0.10	0.013	AC	2.69	6.35	5.10	2.22
LSD$_{05}$ interaction AD	0.21	0.09	0.10	0.013	AD	0.68	0.05	3.04	2.05
LSD$_{05}$ interaction BC	0.11	0.04	0.05	0.006	BC	0.78	0.36	0.41	0.68

* – oscillation coefficient by Gumbel (1947).

This means that the inflorescence branching growth index was proportional to the reduction in standing density. The high variability of the interval given the studies (Kirkegaard et al., 2018; Pontes et al., 2018; Nabloussi et al., 2019; Shafighi et al., 2020) indicates the specific nature of the stress-tolerant response of oilseed radish plants, since the nutrition area factor is considered as a stress in current scientific practice, especially with the intensive formation of phytomass of the plant (Roques & Berry, 2016; Vann et al., 2016; Koscielny et al., 2018; Tariq et al., 2020; Adhikari et al., 2021). For these reasons, the nutrition area is the determining criterion in the technology of oilseed radish cultivation. It is interesting to note that for winter rape, additional branching of the generative part during the growth of the nutrition area of plants is formed mainly in the zone of the main axes of the inflorescence. At the same time, for oilseed radish, such branching containing pods may also are located in the lower lateral tiers removed in height of the stem from the main axis of the inflorescence and lateral branches of 2–7 orders. Such a system of formation of the reproductive part of the plants is clearly evident for the variants in the range of 1.0–2.0 million pcs. ha^{-1} of germinable seeds for row sowing and 0.5–1.0 million pcs. ha^{-1} of germinable seeds for the wide-row sowing.

In contrast to the statement (Kumar et al., 1996; Weiner, 2009; Devi & Sharma, 2017; Li et al., 2017; Mitrovic et al., 2020; Wynne et al., 2020; Schwabe et al., 2021) where the main aspect of the cenosis construction of spring rape, white mustard is the total stand density. Our research proves that it is necessary to consider the combination of row spacing and stand densities in the row. While for optimal combination of branching level and seed productivity of plants we should give preference to those variants for cruciferous species, where the factor of standing density is compensating for the total yield of biomass of plants and seeds and causes a narrower rate of response of changes in a certain morphological and productive indicator.

Studies also proved that it is necessary to consider the combination of the width of inter-row spacing and density of plants in a row, and for an optimal combination of branching level and seed productivity of plants we should give preference to those variants where the factor of standing density is compensating for the total yield of biomass of plants and seeds and causes a narrower response rate of changes in a particular morphological and productive indicator for cruciferous species. This is proved by the conducted evaluation of the share of the influence of factors in the system of dispersion analysis of the variant part of the research. Thus, the maximum value of influence in the dispersion system of branching indicator was obtained for the factor seeding rate - 38.41% and fertilizer - 26.41%.

The value of the seeding method factor in this system of analysis indicates the specificity of the response of oilseed radish plants for different intervals of seeding rate with a row and wide-row sowing. According to the inflorescence branching index, the optimum for this combination in the row sowing is observed at the rate of seeding 2.0 million pcs. ha of germinable seeds, where the difference between the boundary options branching is 5.8–6.7 depending on the fertilizer. As for the wide-row sowing, this optimum is noted for the technological variant of 1.5 million pcs. ha^{-1} This is proved in view of the conducted evaluation of the share of the influence of factors in the system of dispersion analysis of the variant part of the research. Thus, we obtained the maximum value of influence in the dispersion system of branching indicator was obtained for the factor seeding rate - 38.41% and fertilizer - 26.41%. of germinable seeds with the difference between the limit branching options of 6.0–8.2. The technological parameters in the variant of row sowing with the highest seeding rate form a significantly smaller branching interval, which ultimately provides lower levels of reproductive effort of plants. In the variants of wide-row sowing the character of the formation of inflorescence branching was more complicated with the maximum range in the variant 0.5 million pcs. ha^{-1} of germinable seeds at the level of 9.6–11.9 depending on the fertilizer, which at the highest value in the variant system of reproductive effort potentially formed lower levels of both the biomass yield and the seed yield, based on the functional product of standing density on the individual bioproductivity of plants. In our opinion, the value of the compensatory index of plants, which is indicated by the total branching of inflorescence, should be used in determining the optimal technological variants of pre-sowing construction of cruciferous crops agrocenosis. This is clearly confirmed by the results presented and indicated in a number of several similar studies (Nandaa et al., 1996; Chaniyara et al., 2002; Shahin & Valiollah, 2009; Shekhawat et al., 2012; Pandey et al., 2015; Bennett et al., 2017; Kayaçetin et al., 2018; Chang et al., 2020; Adhikari et al., 2021). On the other hand, in several studies the emphasis in determining the technological parameters of pre-sowing formation of cruciferous crops agrocenosis is reduced to the analysis of the effectiveness of their recommended levels and the analysis of additional branching is done in terms of its regulation using mineral fertilizers and sowing timing (Bhajan et al., 2015; Lääniste et al., 2016; Ahmad, 2017; Ahmad et al., 2021). In our opinion, this approach does not allow us to develop a full-fledged adaptive strategy for the formation of the cenosis of this group of crops, based on the determined specifics of interaction between the area of plant nutrition and the level of their mineral nutrition for the oilseed radish.

The formation of morphological parameters of the pod and features of its anatomy depended on the technological factors under study. We noted a constant dynamic of consistent increase in pod length both in the dynamic row both in the section of row sowing and of wide-row sowing. The range of pod length values within the studied variants indicates a high variation component of pod morphometry in oilseed radish. At the same time, we found that the variability increases with the growth of the nutrition area of plants in combination with additional mineral nutrition. For example, the growth of pod length in comparison with unfertilized variants 0.5 and 4.0 million pcs. ha^{-1} of germinable seeds averaged 36.43% for the period of research while for fertilized variants with the fertilization rate of 90 kg N ha^{-1}, 90 kg P ha^{-1}, and 90 kg K ha^{-1} averaged 43.9%. The variability of pod length in the system of variants of row sowing in general is 7.82–10.35% lower than the variability in the system of variants of wide-row sowing. This once again emphasizes the character of oilseed radish stress-strategy due to the inherent features of additional branching and tier formation of additional generative shoots, confirming those noted in several studies (Li et al., 2016; Abley et al., 2016; Parvaiz, 2017; Fujikura et al., 2018; Ahmadzadeh rt al., 2019; Abdo Bakri & Al-dhubibi, 2021). This means that an increase in the area of plant nutrition with additional mineral nutrition provides in oilseed radish both growth of the total length of the pod and variation of its linear size in oilseed radish. At the same time, according to the value of the oscillation coefficient, the total share of variability of both pod diameter and thickness of its walls in comparison to their average value for each separately taken variant at maximum density of oilseed radish plants by row sowing method is significantly higher than for variants of lower technological gradations of the same sowing method. For the wide-row sowing method, the growth tendency of the oscillation coefficient is reversed with an increase in the area of plant nutrition and fertilizer. This confirms the earlier conclusions concerning the general stressfulness of technological gradations of oilseed radish agrocenosis formation and the specific compensatory properties of the plant itself when optimizing the area of plant nutrition with increasing fertilizer. At the minimum plant nutrition area mineral fertilizers are an additional stress factor for standing density at the level of 3.0–4.0 million pcs. ha^{-1} of germinable seeds. Similar conclusions for several variants of seeding rates are made in studies of white mustard (Akbar et al., 2007; Vovchenko & Fursova, 2012; Shekhawat et al., 2012) and winter rape (Khan et al., 2018; Abdo Bakri & Al-dhubibi, 2021; Hashim & Mahmood, 2021).

We also noted a certain specificity of the formation of anatomical features of the oilseed radish pod depending on the system of oilseed radish cenosis construction. With a generally stable growth of both the pod diameter and its wall thickness, the growth rates of these indicators were significantly higher than for the pod length indicator. So, for limit values of technological options 4.0 million pcs. ha^{-1} of germinable seeds without fertilizers and 0.5 million pcs. ha^{-1} of germinable seeds with fertilization rate of 90 kg N ha^{-1}, 90 kg P ha^{-1}, and 90 kg K ha^{-1}, the increase in pod diameter was 60.34%, in pod wall thickness was 85.41%. This means that the improvement of nutritional conditions both with additional mineral nutrition and optimization of soil nutrition contribute to the activation of growth rates of anotomic morphometry of the oilseed radish pod. These rates are determined for oilseed radish higher than similar rates for several cruciferous crops noted in the some studies (McGregor, 1981; Habekotté, 1993; Child et al., 2003; Kuchtová & Vašák, 2004; Miri, 2007; Bennett et al., 2011; Kuai et al., 2016). It is also noted that morphological and anatomical changes of pods are characteristic for winter rape with optimization of plant conditions, including edaphic nature, which leads to the formation of plants of another productive morphotype (Tayo & Morgan, 1979; Tan et al., 2006; Zhuikov, 2014; Li et al., 2017). Our data also confirm this fact. Given the levels of development of the generative part and the potential of seed productivity, the oilseed radish agrocenosis formed by the seeding rates of 2.0–4.0 million pcs. ha^{-1} of germinable seeds, should be attributed to forage use, where a high leafy mass with a low proportion of seeds is formed. Agrocenoses formed in the rate interval of 1.0 million pcs. ha of germinable seeds in a row and 0.5–1.5 million pcs. ha^{-1} of germinable seeds at wide-row sowing provide formation of seed type plants. Given the fact that the thickness of the fruit walls of cruciferous crops is a limiting argument regarding the ergonomics of threshing (Li et al., 2012) and control of seed loss during harvesting (Luo et al., 2015), i and has a desirable interval for many cruciferous crops (Tan et al., 2006; Davies & Bruce, 2007; Pu et al., 2013; Yu et al., 2020; Qing et al., 2021), we identified certain technological limitations on ensuring seed production of oilseed radish. Given the specificity of threshing pods of other cruciferous crops with pods that do not open during ripening (Qing et al., 2021), for oilseed radish the diameter of the pod is desirable in the range of 9.0–10.0 mm with a thickness of the pod walls of 1.3–1.8 mm. Based on these positions, the optimum of seed crops of oilseed radish is formed in the version of 1.0 million pieces ha^{-1} of germinable seeds of row sowing - 1.5 million pieces ha^{-1} of germinable seeds of wide-row sowing.

We should note that in accordance with the conducted analysis of the influence of factors in the overall scheme of dispersion analysis (Dunstone & Yager, 2009), we found that the hydrothermal conditions of the growing season with a level of determination of 32.32% are the most determinative in the formation of the length of the oilseed radish pod and the least determinative in the formation of the number of branches of the generative part of plants (11.81%). At the same time, the leading role of seeding rate - 26–31% and seeding method 26–29% in the formation of morphological and anatomical features of the pod was noted. From the position of the formation of morphology and anatomy pods mineral fertilizers had a compensatory nature with the share of influence at the level of 8–12%. However, their influence on branching and formation of the corresponding plant morphotype was significant and amounted to 26.41%. The data obtained prove the high adaptive potential of oilseed radish concerning the resistance to high temperatures and drought on the intensity and effectiveness of the process of formation of the reproductive organs of plants. Especially if we compare similar data for spring and winter rape (Weymann et al., 2015; Nowosad et al., 2016; Chen et al., 2020), white mustard (Bose, 1973; Vovchenko & Fursova, 2012; Pandey et al., 2015) and other cruciferous species (Annisa et al., 2013; Bhajan et al., 2015; Hasanuzzaman, 2020).

Deeper analysis of the factor system of interaction of experience factors against the background of hydrothermal conditions of the period of pod formation can be carried out by analyzing the regression graphical material in the form of reaction surfaces (Fig. 4). According to this, the pod length of oil radish (Fig. 4 (a, b)) had a complex differential nature depending on hydrothermal coefficient (HTC) of pod formation period and sowing rate with maximum of 1.2–1.6, sowing rate in the range 0.5–1.5 million pcs. ha^{-1} of germinable seeds with fertilizer 1.5–3.0 expressed in index form in vriants without fertilizes. The pod diameter (Fig. 4 (c, d)) reached its maximum value at the HTC value of 1.2–1.4 at the seeding rate of 0.5–1.5 million pcs. ha^{-1} of germinable seeds. The effect of mineral fertilizers on the formation of pod diameter was determined by the interaction of HTC and fertilizer dose. At HTC 1.5–1.6 the growth of stem diameter had an intensive growth nature with the minimum index fertilizer expression at 0.5. For HTC 1.0–1.4 the intensity of increase of index was marked by index fertilizer at value 1.0. The HTC level < 0.8 canceled the positive effect of mineral fertilizers.

Pod wall thickness (Fig. 4 (e, f)) had a similar pattern of formation in the HTC system and seeding rate, but the response of recall had a tighter technological regulation. Thus, the maximum values of pod wall thickness were noted at sowing rate in the range of 0.5–1.0 million pcs. ha^{-1} of germinable seeds at HTC between 1.2–1.4 and index fertilizer in the range of 2.0–3.0.

Thus, the maximum reproductive architectonics of the oil radish plants is formed under moderate and sufficient moistening for the pod formation stage with wide-row sowing at a sowing rate in the range from 0.5 to 1.5 million pcs. ha of germinable seeds. At the same time, the agrocenotic productivity of 1 m^2 of sowing at the achievable level of the technological variant of pre-sowing construction is 1.5 million pcs. ha^{-1} of germinable seeds. The full positive effect of mineral fertilizers will be observed at HTC of 1.0 or higher. Fertilizer effect by HTC in the range 0.4–0.8 will be found reasonable by seeding rates in the range of 0.5–1.0 million pcs. ha^{-1} of germinable seeds using a wide-row sowing method. In technological variants with the rate of seeding 3.0–4.0 million pcs. ha^{-1} of germinable seeds, positive effect of fertilizers will be predicted by the effect on the reproductive part of oilseed radish plants at the level of HTC in the range of 1.6–2.0. The obtained results showed a less identical dependence on the hydrothermal conditions of the fruiting period at the stage of the beginning of pod formation established for other cruciferous crops (Angadi et al., 2000; Robertson et al., 2002; Morrison & Stewart, 2002; Sabaghnia et al., 2010; Kirkegaard et al., 2018;

Hasanuzzaman, 2020). However, at later stages of pod formation known as the 'yellow-green pod phase', the dependence decreases and changes its nature of influence on the formation of its anatomical features, in particular wall thickness.

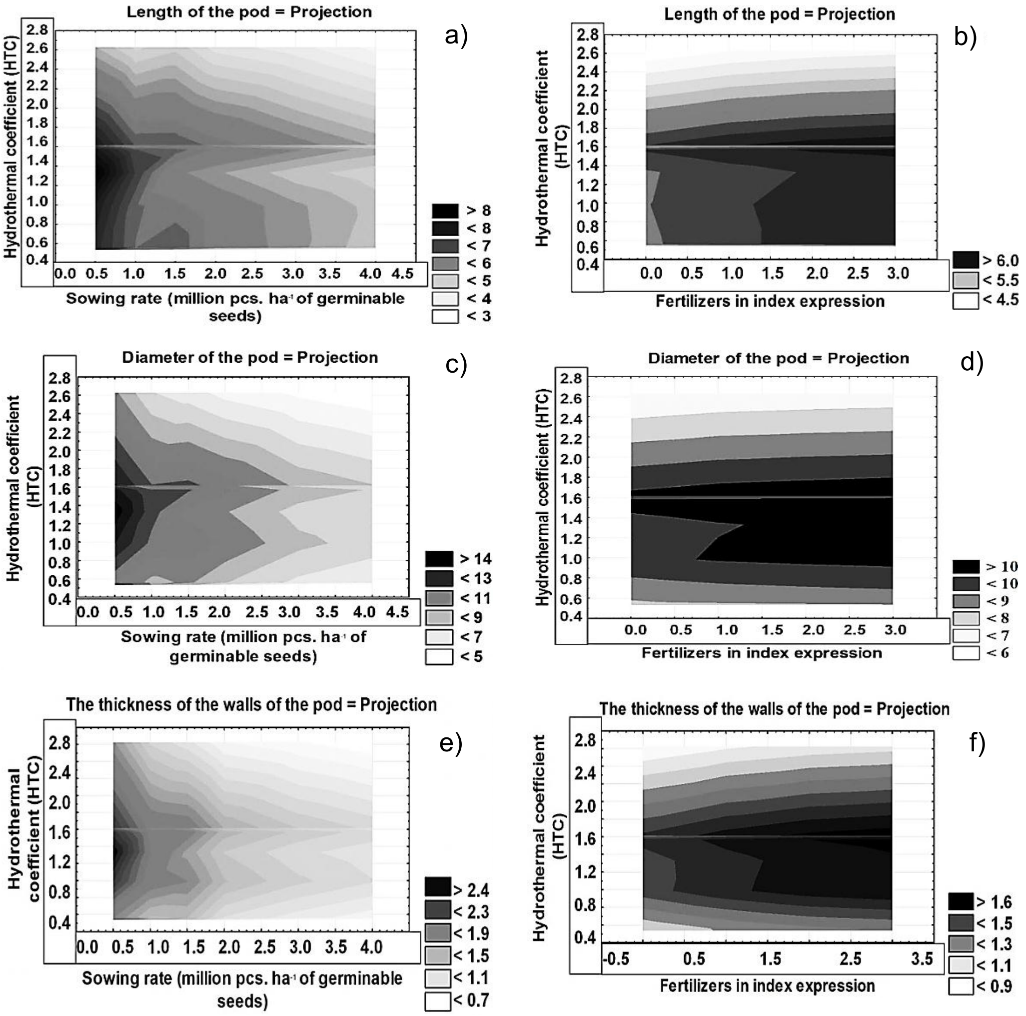
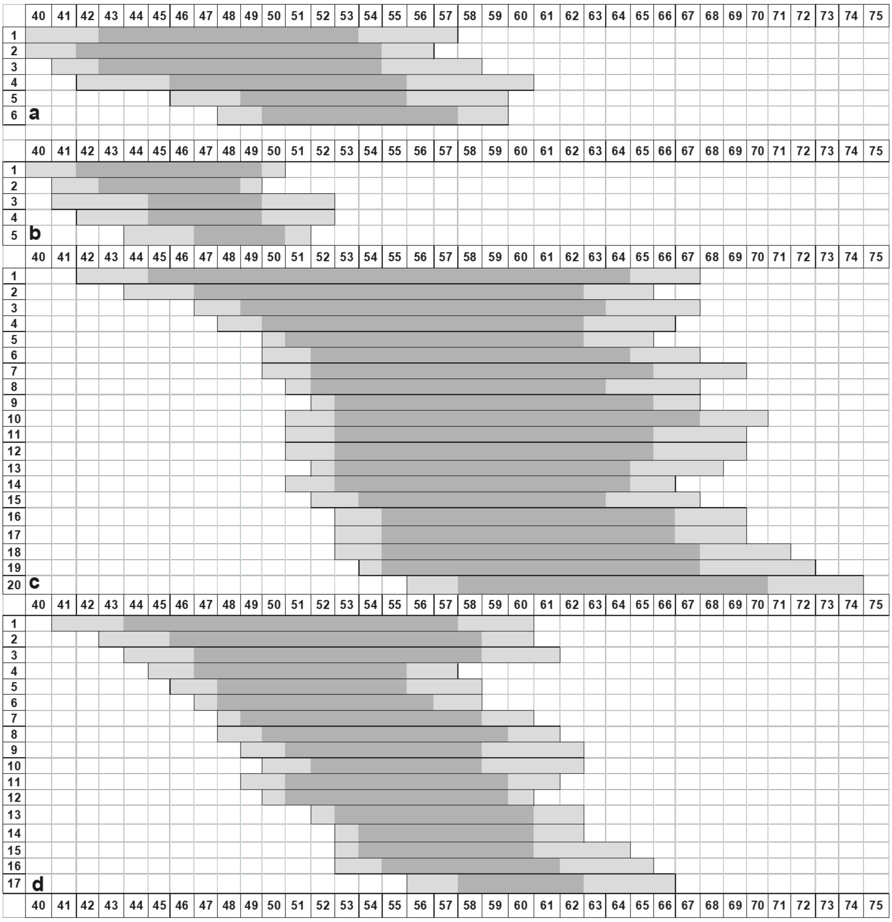


Figure 4. Graphs of projections of morphological features of the oilseed radish plant pod at the yelow pod phase (BBCH 79–81) depending on hydrothermal conditions of vegetation and technological parameters of its agrocenosis construction (averaged for three varieties), 2013–2020. (Fertilizers in index expression: $N_0P_0K_0$ – 0; $N_{30}P_{30}K_{30}$ – 1; $N_{60}P_{60}K_{60}$ – 2; $N_{90}P_{90}K_{90}$ – 3).

Our long-term studies have shown that the averaged nature of the consideration of morphometric parameters of oilseed radish pods does not allow us to fully characterize the patterns of their formation, especially given the high levels of heterocarpy that is typical for cruciferous crops (Dorofeev, 2004; Gangapur et al., 2009; Hasanuzzaman, 2020; Khan et al., 2022). The long-term records of the pod morphometry of the oilseed radish varieties under study during the phase of their yellow-green ripeness allowed us to evaluate the spatial and temporal heterogeneity in the formation of both the inflorescence as a whole and its particular lateral branches. This leads to morphological heterogeneity in the structure of the fruit of oil radish plants due to certain principles of heterocarpy by distancing from the main axis of the inflorescence, features of growth in a certain direction from the base of the main axis of the inflorescence or the corresponding lateral branches to the top of these structures. Differences in the onset of phenological stages of flowering in the indicated acropetal direction, which against the background of successive lengthening of both the head and lateral axes of the inflorescence provides differentiation in flowering depending on their spatial location by height position on the corresponding branching. This creates different conditions for the formation of pods due to changes in hydrothermal conditions during their formation and growth, as well as due to different duration of their morphogenesis. Unlike rape and white mustard, which have a similar pattern of flowering and fruiting (Habekotté, 1993; Wright et al., 1995; Pinet et al., 2015; Hunter et al., 2017; Halevy et al., 2019) the possibility of simultaneous flowering of close tiers of flowers in height has been established for oil radish, which provides a sharp reduction in the duration of flowering of the corresponding axes against the background of an active increase in high average daily temperatures and a deficit of moisture supply. In fact, each inflorescence axis may show a certain specificity in the total duration of its flowering depending on the nature of weather conditions with a certain general reduction in the duration of flowering of the lateral branches of the inflorescence of the corresponding orders in comparison with its main axis (Fig. 5).

Figure 5. Flowering pattern and formation of oilseed radish pods within the main axis of the inflorescence (1 – beginning of flowering at the base of the main axis; 2 – formed pods at the base of the main axis of the inflorescence; 3, 4 – middle zone of the main axis of the inflorescence with consecutive decrease in age of formed fruit elements toward the apex; 5, 6 – apical part of the main axis of the inflorescence with apical placement of flowers in the flowering stage), 2020.

We can confirm these conclusions by the chart of periodization of flowering of oilseed radish plants within two technological limits of its agrocenosis construction of 0.5 and 4.0 million pcs. ha^{-1} of germinable seeds with application of fertilization rate of 90 kg N ha^{-1}, 90 kg P ha^{-1}, and 90 kg K ha^{-1} (Fig. 6) in the comparison of cardinally opposite years in terms of the HTC period of pod formation. The variant with the maximum rate of fertilization was chosen considering the methodology of studying the maximum amplitude of variability of plant morphological signs in accordance with several recommendations (Akbar et al., 2007; Bennett et al., 2017). These charts allow us to assert that the oilseed radish plants are characterized by a variegated system of the duration of flowering of the lateral branches of the inflorescence in comparison with the main axis.



*The variation component from the average is presented in the form of light gray columns for each branch of the inflorescence

Figure 6. Days to flower and duration of flowering of individual inflorescences from plants with fertilization rate of 90 kg N ha^{-1}, 90 kg P ha^{-1}, and 90 kg K ha^{-1} (vertical axis – number of the branch of inflorescence; horizontal axis – days after seeding; a – 4.0 million pcs. ha^{-1} of germinable seeds (row sowing), 2020; b – 4.0 million pcs. ha^{-1} of germinable seeds (row sowing), 2015; c – 0.5 million pcs. ha^{-1} of germinable seeds (wide-row sowing), 2020; d – 0.5 million pcs. ha^{-1} of germinable seeds (wide–row sowing), 2015.

At the same time, hydrothermal conditions during flowering determine the total duration of flowering of each axis and the total duration of flowering. Thus, under the 2015 conditions with the HTC value for the pod formation period of 0.535, the period of both plants with the maximum morphological variability (Fig. 1) at the seeding rate of 4.0 million pcs. ha^{-1} of germinable seeds and plants with the maximum morphological variability at the seeding rate of 0.5 million pcs. ha^{-1} of germinable seeds was 8 and 5 days shorter than for the 2020 conditions with the corresponding HTC value of 1.331. We also found that improvement of hydrothermal conditions of pod formation period differently affects both the number of branches for both extremely distant variants of studies in their overall scheme, and the variation component of the average values of flowering duration. At the lowest value of HTC, there is a total reduction in the number of branches and an increase in the spread of the duration of flowering of each branch (its variation component). Similar results have been observed in a number of cruciferous crops in other studies (Habekotté, 1993; Sabaghnia et al., 2010; Zhuikov, 2014; Hasanuzzaman, 2020).

In addition, stressful conditions during the period of pod formation provide a shift in the start date of flowering of different branches, increasing the differentiation of phenological stages of flowering within the whole inflorescence and reducing the overall phenotype of flowering periodization in the aggregate for all branches. According to a number of studies, such nature of changes in phenological stages of flowering in cruciferous crops is due primarily to the level of abortion of flowers on each branching, especially those that fall under the peak values of high temperatures at the low moisture observed and in our studies. However, in our opinion, this does not fully explain the process of differences in flowering for different types of plant inflorescence structure. Based on our studies, we believe that the influence of stressful conditions is caused by three factors. The first of them concerns already mentioned hydrothermal maximums or minimums in the period of pod formation, the second is associated with the density of plant placement per unit area, the third is related to the features of flowering within each branching. Regarding the density of plant placement, as indicated earlier, in oilseed radish it affects the overall architectonics of plants with formation of a regular morphological series of different types of plant inflorescence structure within each technological variant under study. On this basis, the general scheme of the spatial structure of the main axis and lateral branches of the inflorescence, as well as their altitudinal placement, changes significantly. In particular, the sowing rate of 4.0 million pcs. ha^{-1} of germinable seeds (Fig. 2) is characterized by formation of an average of 5–6 common branches of inflorescence with their apical placement (compact type of generative part), and the variant with the sowing rate of 0.5 million pcs. ha^{-1} of germinable seeds forms 14–20 branches with a wide range of their height placement (spatial type of generative part). As a result, we saw high variability in the dates of the beginning and duration of flowering of each of the axes with a subsequent decrease in the density of standing plants, especially against the background of high levels of additional mineral nutrition. In the overall result, branch axes of 6–20 order (depending on the variant of agrocenosis construction), forming a smaller number of flowers against the background of general reduction of stages of their development, have a significantly lower average total duration of flowering.

At the same time for oilseed radish, we determined the feature of one-stage flowering of several axes close in order (in the graph these are the chart bars with the same coordinate beginning), which is inherent in plants with lower density per unit area. According to several studies (Bose, 1973; Masierowska et al., 2003; Osborn & Lukens, 2003; Wang et al., 2011; Raman et al., 2013; Shah et al., 2018; Andrimont et al., 2020; Sun et al., 2021; Zhang et al., 2021), the difference in the timing of flowering on different axes and the long flowering period of an individual plant contribute to the intensive influence of weather conditions on all the processes of fruit formation. This is confirmed by the results of factor analysis in the scheme of variance processing of research results (Table 3), where the share of year conditions in terms of their influence on the morphology and anatomy of pods is 26–32%. In fact, analyzing each axis by the flowering pattern, pod development, the level of their abortiveness (in the presence of the stem without a pod (Xiujuan, 2011)) in cruciferous plants, we can conclude about the intensity of stress factors in the cycle of phenological development of oilseed radish. The maximum levels of abortion of pod rudiments under unfavorable conditions are observed at the microstage BBCH 67-71 during the period from complete petal fall to the stage when 10% of pods reach the final size. In view of the above arguments, at different stages of flower and fruit formation, the hierarchical structure of the oil radish inflorescence has corresponding tier features, which are expressed both in the difference in stages of pod and seed formation and in the morphological parameters of the latter gradation from the inflorescence base to its apex. Even during the brown pod phase (BBCH 83-87), the presence of flowers on the apex part of the generative part of oilseed radish plants is noted.

The above-mentioned studied features in the stages of flowering within the inflorescence of oil radish allow us to make a statement about the different stages of morphological development of the pods within the spatial structure of the inflorescence itself. The above multistage is based on the already mentioned biological features of flowering stages within the lateral branches of the inflorescence of oilseed radish plants depending on its inflorescence structure. Primarily, this is related to the peculiarities of inflorescence formation due to elongation of its main axis and gradual formation of new flowers in the direction from the base of the pedicel to its apex, which is traced both on the main axis of the inflorescence and on its lateral branches and inflorescences of lateral shoots. In addition, the above features of the formation of the spatial structure of inflorescence cause a long period of fruit formation and seed ripening and a significant difference in the time of pod formation and duration of seed ripening depending on its placement in the inflorescence: fruit elements of the lower placement have respectively a longer formation period and, consequently, higher values of morphological development than fruit elements of the middle and especially the upper tier. These processes of pod formation are evident already at the stages of the beginning of oilseed radish fruit formation and are completed in stages with different degrees of heterocarpy within different orders of inflorescence, which is clearly confirmed by the data shown in the Fig. 7.

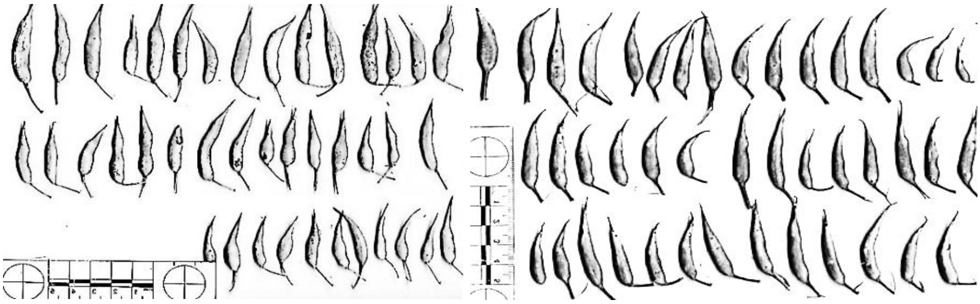


Figure 7. Dynamic rows of pods within the first three branches of the inflorescence of oilseed radish plant (variety ‘Zhuravka’) during the green pod phase BBCH (75–77) for the variant 0.5 million pcs. ha^{-1} of germinable seeds with fertilization rate of 90 kg N ha^{-1}, 90 kg P ha^{-1}, and 90 kg K ha^{-1} (left position – 2015, right position – 2020, (each row of pods corresponds to one of the branches, in the direction from the base to the top of the branch)).

Table 4. Regression model for estimating oilseed radish pod length depending on its placement on the inflorescence axis in the order of its botanical tropation, 2013–2020

Model no.	Form of model tested	Fitted coefficients and costant				Test of the models			
		a	b	c	d	r	R^2	Sr	RMSE
a	$y = (a+bx)/(1+cx+dx^2)$	8.901E-003	9.221E+000	7.326E-001	1.420E-001	0.999	0.998	0.144	0.321
b	$y = a\exp((-(b-x)^2)/(2c^2))$	6.249E+000	3.503E+000	7.832E+000		0.968	0.936	0.179	0.809
c	$y = (a+bx)/(1+cx+dx^2)$	1.097E-002	1.005E+001	7.624E-001	1.745E-001	0.986	0.972	0.407	0.851
d	$y = a\exp((-(b-x)^2)/(2c^2))$	6.107E+000	3.427E+000	4.918E+000		0.949	0.902	0.289	1.112
e	$y = (a+bx)/(1+cx+dx^2))$	9.762E-004	1.579E+001	1.635E+000	1.592E-001	0.991	0.982	0.278	0.453
f	$y = a\exp((-(b-x)^2)/(2c^2))$	8.256E+000	2.161E+000	1.989E+001		0.985	0.970	0.272	0.917
g	$y = (a+bx)/(1+cx+dx^2)$	5.421E-002	1.545E+001	1.014E+000	1.314E-001	0.960	0.922	0.677	1.133
h	$y = a\exp((-(b-x)^2)/(2c^2))$	8.233E+000	2.568E+000	1.20E+001		0.956	0.914	0.695	1.296

Models: a, b – respectively Rational Function and Gaussian Model for the main axis of the inflorescence in the technological variant of 4.0 million pcs. ha^{-1} of germinable seeds without fertilizers; c, d – respectively Rational Function and Gaussian Model averaged for 2nd-6th order lateral branches in the technological variant of 4.0 million pcs. ha^{-1} of germinable seeds without fertilizers; e, f – respectively Rational Function and Gaussian Model for the main axis of the inflorescence the technological variant of 0.5 million pcs. ha^{-1} of germinable seeds without fertilizers; g, h – respectively Rational Function and Gaussian Model averaged for 2nd–20th order lateral branches in the technological variant of 0.5 million pcs. ha^{-1} of germinable seeds without fertilizers (The X axis is the sequence number of the pod from the base to the apex of the corresponding axis of inflorescence branching, the Y axis is the pod length (cm)).

We confirmed our earlier conclusions about the peculiarities of pod morphometry within the inflorescence axes and analysis with the selection of the functional addiction of pod length depending on its placement in the inflorescence, the results of which are presented in Table 4 and Fig. 8. According to the conducted functional selection by R^2 and RMSE criteria, we found that the nature of pod length formation is most fully described by two types of power functions, namely, Rational Function and Gaussian Model.

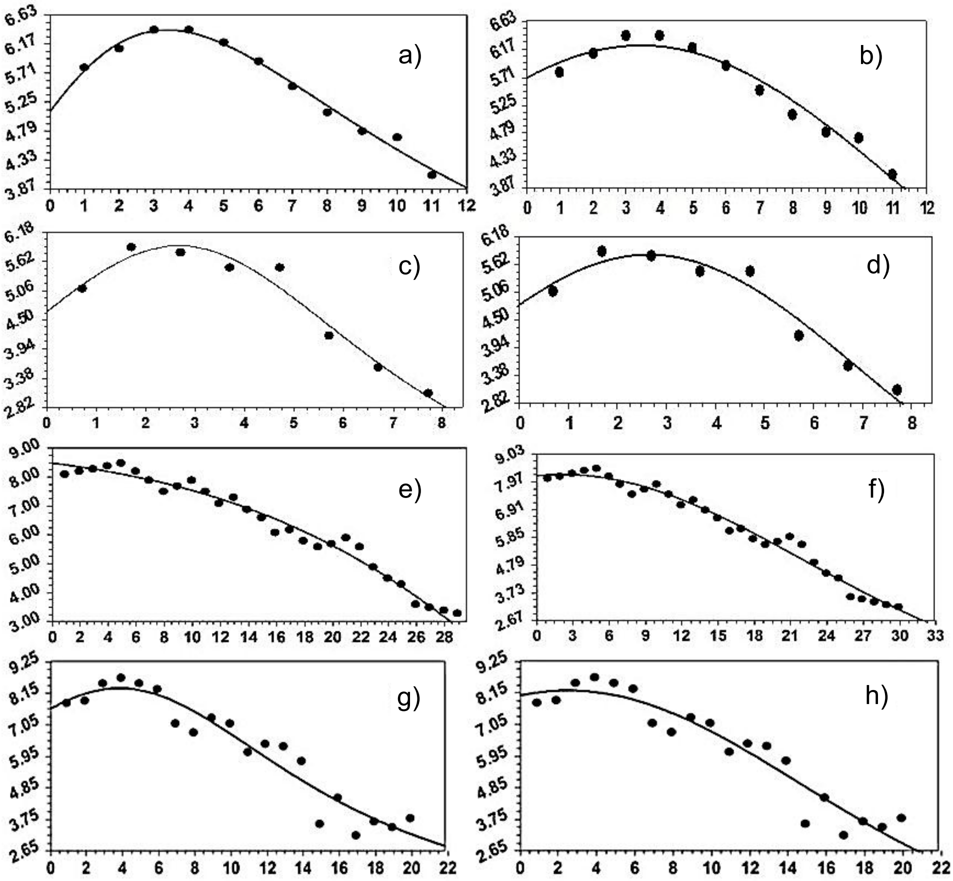


Figure 8. The graphs of mathematical models of changes in pod length on the corresponding branches of the inflorescence in order from the base to the top of the inflorescence are averaged for the three studied varieties of oilseed radish at the phase of yellow-brown pod ripeness (BBCH 86–87) for the period between 2013–2020 (mathematical interpretation of the e–h models which is shown in Table 4).

Application of other function variants had significant values of correlation dependence of factors with significantly higher indices of standard error and RMSE criterion. The indicated dependences indicate a consistent constant decrease in the linear size of the oilseed radish pod from the base to the apex of both the main axis and the lateral branches of the inflorescence. Fewer points of determination in the plots of lateral branches (Fig. 8 c, d, g, h) and higher levels of dispersion of points relative to the predictive model curve indicate both a smaller number of pods on lateral branches in comparison to the main axis of the inflorescence, and an increase in variation of linear pod size within these branches especially in low plant density variants at maximum mineral fertilization. This creates a complex spatial structure of oilseed radish pod morphometry both in the acropetal direction from the base to the apex of each inflorescence axis and in the radial direction from the main inflorescence axis to the corresponding lateral branches. The growth of variation in morphological size of the pod increases during formation of plant morphotypes in technological variants of low density at high levels of fertilization.

The complex system of dependence of the second stage indicates the possibility of formation within the main axis and lateral branches of intervals with insignificantly different parameters of pod length (belts of the same morphometry) as well as the oscillatory nature of the appearance of significantly different morphological pods within a similar morphometric interval. Such features are indicated in several studies (Cao et al., 2006; Skriabin et al., 2006; Jullien et al., 2011; Bennett et al., 2017; Zhang et al., 2018, 2020). However, in contrast to these studies, it relate to revealing types of pods and are based on empirical assumptions. Our calculations are based on long-term estimates of the morphometry of pods from the view of the spatial structure of the inflorescence. This allows to accurately predict the morphological parameters of oilseed radish pods depending on their spatial location in the inflorescence, given the applied agro-technological variants for constructing its agrocenosis.

Such features are most noticeable at low values of HTC for variant with a high sowing rates 3.0–4.0 million pcs. ha^{-1} of germinable seeds of row sowing or, on the contrary, at high values of HTC for variant with a low sowing rates 0.5–1.0 million pcs. ha^{-1} of germinable seeds. This is clearly demonstrated by comparing models a–b and e–f (Fig. 8). Based on a detailed analysis of such intervals of variation in morphological parameters of the oilseed radish pod, we identified three tiers in the spatial structure of the inflorescence of oil radish, which statistics for two limiting technological options for the construction of its cenosis (Table 5) allows us to assess the specific patterns of formation of fruit elements of oilseed radish. Regarding the formation of the inflorescence layer of cruciferous crops was noted in studies McGregor (1981), Habekotté (1993), Bowman et al. (1999), Chub & Penin (2004), Zhang et al. (2018). Despite the fact that there is a certain layering in cruciferous inflorescences, this issue was considered in these publications from general approaches to varying the morphology of pods in the overall structure of the inflorescence without assessing the development of certain zones, their percentage concentration in the inflorescence structure and statistical assessment of morphological parameters. The question of the factors that determine the formation of inflorescence stratification by morphological development of pods is poorly studied. Attempts to develop and explore these important issues have been made in research of Khmelyanchyshyn (2005), Xiujuan (2011), Oleksy et al. (2018), Matar et al. (2021).

Table 5. Statistical evaluation of variability of morphological development parameters of oilseed radish pods of 'Zhuravka' variety at brown pod phase (BBCH 88-90) within reproductive branching zones (average for 2013–2020 for the annual sample $n = 500$ with the general totality of observations $N = 4{,}000$)

Inflorescence zones	Pod length (l), cm			Pod diameter (d), mm			Pod wall thickness (hw), mm		
	R, cm	V, %	X_{av}, cm	*R*, mm	V, %	X_{av}, mm	*R*, mm	V, %	X_{av}, mm
Row sowing with a sowing rate of 4.0 million pcs. ha of germinable seeds $N_0P_0K_0$									
Lower	3.98–7.52	10.61	5.15 ± 1.18[*]	4.80–8.50	9.78	7.55 ± 1.27	0.52–1.77	18.29	1.33 ± 0.27
Middle	2.17–6.09	11.15	4.36[a] ± 1.21	4.14–9.06	11.25	6.78[b] ± 1.41	0.33–1.42	18.50	1.03[c] ± 0.25
Upper	1.97–5.33	13.52	4.12[a] ± 1.59	3.57–7.58	10.80	5.63[a] ± 1.37	0.68–1.97	18.68	0.91[b] ± 0.33
Row sowing with a sowing rate of 4.0 million pcs. ha of germinable seeds with $N_{90}P_{90}K_{90}$									
Lower	3.19–7.84	12.35	5.29 ± 1.56	4.53–8.72	11.44	7.82 ± 1.44	0.52–1.95	16.74	1.12 ± 0.27
Middle	2.26–6.94	11.63	4.85[a] ± 1.37	3.95–9.84	11.75	7.18[a] ± 1.39	0.41–1.78	17.53	0.98 ± 0.34
Upper	2.02–5.62	12.97	4.43[a] ± 1.51	4.02–6.75	13.25	5.23[a] ± 2.05	0.38–1.99	20.56	0.75[b] ± 0.51
Wide-row sowing with a sowing rate of 0.5 million pcs. ha of germinable seeds $N_0P_0K_0$									
Lower	3.50–10.40	14.28	6.89 ± 1.67	5.70–13.20	12.37	12.65 ± 1.88	0.75–2.38	16.89	2.03 ± 0.28
Middle	3.45–9.08	14.49	6.08[b] ± 1.73	5.11–11.87	11.55	10.87[b] ± 1.89	0.71–2.14	17.82	1,83[b] ± 0.37
Upper	2.54–7.71	15.08	5.69[a] ± 1.89	3.89–10.60	16.37	8.81[a] ± 2.10	0.63–2.32	18.29	1.62[a] ± 0.53
Wide-row sowing with a sowing rate of 0.5 million pcs. ha of germinable seeds with $N_{90}P_{90}K_{90}$									
Lower	4.17–10.25	15.87	7.63 ± 1.79	6.15–13.84	12.55	12.85 ± 1.73	0.85–2.88	18.83	2.39 ± 0.34
Middle	3.23–10.07	15.12	6.98[a] ± 1.58	5.24–13.07	14.76	11.85[a] ± 2.28	0.81–2.52	19.08	2.11[b] ± 0.45
Upper	3.23–7.89	19.72	5.82[a] ± 2.09	4.18–11.19	17.20	9.37[a] ± 2.54	0.71–2.57	19.55	1.80[a] ± 0.54

Significance levels of the middle and upper zone data versus the lower zone: *a* – 0.1%; *b* –1%*;* c– 5%.

* – arithmetic mean error for $a \leq 0.05$.

The presented results allow us to conclude about the tiered heterocarpy in oilseed radish, which leads to differentiation of pods by the main parameters of morphological development both in variants of the highest technologically applicable density of its agrocenosis of 4.0 million pcs. ha^{-1} of germinable seeds and in variants of maximum allowable technological liquefaction by sowing rate of 0.5 million pcs. ha^{-1} of germinable seeds. The most variable trait was pod wall thickness in the middle zone with a range from 0.41 to 1.49 mm, which corresponds to an average gradation of variation of 18–20%. The variability of pod diameter was the lowest with a coefficient of variation within the studied variants of 9.34–14.5%. It should be noted that several studies reported signs of fruit heterocarpy in cruciferous plants and its tiered expression in the inflorescence (Khmelyanchyshyn, 2005; Naomab, 2008; Lu et al., 2010; Xiujuan, 2011; Li et al., 2016, 2020; Zhang et al., 2018). In evaluation of morphometry of formation of features behind the tiers of inflorescence in the direction from base to apex the following regularities should be noted: reduction of pod length when its shape changes in the interval by 15.8–24.6% in comparison of the upper tier to the lower tier, reduction of pod diameter in the interval by 6.5–11.8% in comparison of the upper tier to the lower tier, increase of pod wall thickness in the middle part in the interval by 8.3–9.6% for the same level of comparison.

We found that the use of mineral fertilizers contributes to the increase in the manifestation of heterocarpy in oilseed radish by increasing both the actual linear size of the pod and the range of values of the indicators. The maximum effect of fertilizers in terms of variability of fruits is noted precisely in the variants with a lower density of cenosis. In cenoses with maximum plant density due to cenotic pressure, the variability of morphological parameters was lower in the value of the coefficient of variation and, accordingly, the significance of morphological differences in the fruit within the inflorescence was less evident. The evaluation of the intensity of development of these tiers of different morphometric pods in oilseed radish varieties in the interval of years of research also confirms the earlier conclusions (Fig. 9). According to this graph, the expression of the formation of individual zones of the generative part of oilseed radish plants depended significantly on the technological variant of pre-sowing formation of its agrocenosis. For the variant 4.0 million pcs. ha^{-1} of germinable seeds without fertilizer application in comparison with the data of the variant 0.5 million pcs. ha^{-1} of germinable seeds against the background of $N_{90}P_{90}K_{90}$ application, the share of the lower zone was 1.2–1.6 times less, the share of the upper zone was also less in 1.1–1.3 times, and the share of the middle zone was 1.1–1.3 times more, depending on the year of research.

The fluctuating nature of the ratio of zones was more pronounced at lower density of standing on the background of additional mineral nutrition. Thus, the sowing rate of 4.0 million pcs. ha^{-1} of germinable seeds on unfertilized background interval of the proportion of the lower zone in the interval of years of study was 14.2–26.3%, the middle zone 58.9–69.7%, the upper zone 8.6–19.1%. A similar interval for the variant 0.5 million pcs. ha^{-1} of germinable seeds against the background of $N_{90}P_{90}K_{90}$ application was 21.8–36.7%, 48.6–56.4, 12.6–28.7% respectively. This confirms the earlier conclusions about the effect of sowing rate and sowing method on the variability of linear size of the pod given the established range of values and oscillation coefficient, which increase both when optimizing the nutrition area and the fertilization of oilseed radish plants (Table 3). It should be noted that the development of the lower and especially the upper zones of the generative part of oil radish plants allows us to conclude about the general stressful weather conditions of the year.

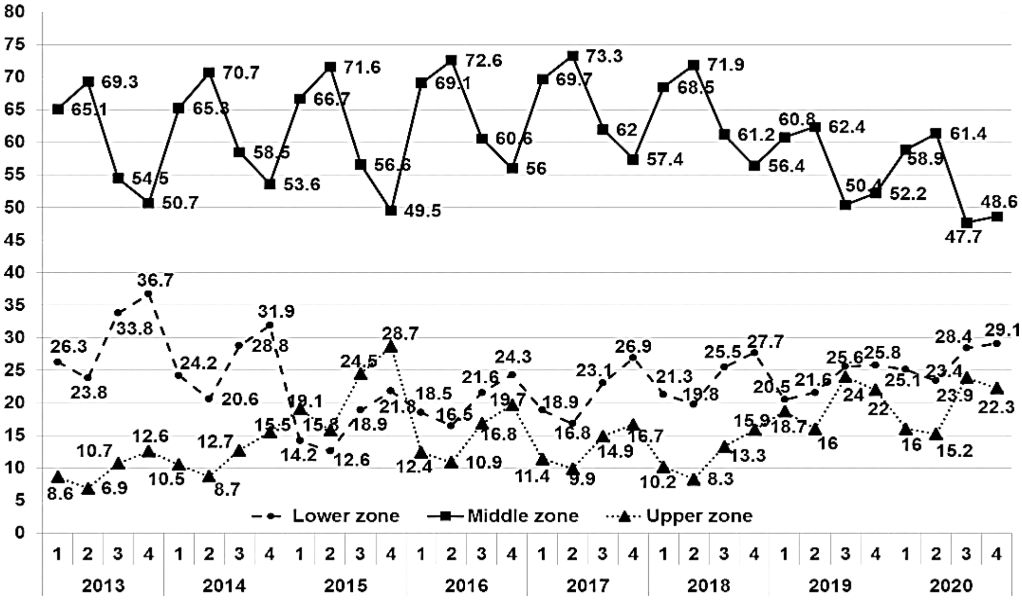


Figure 9. Share of inflorescence zones of oilseed radish plants by indicators of morphological development of pods, depending on technological options for the design of its agrocenosis, 2013–2020 (research variants: 1 – 4.0 million, row $N_0P_0K_0$; 2 – 4.0 million, row + $N_{90}P_{90}K_{90}$; 3 – 0.5 million, wide-row $N_0P_0K_0$; 4 – 0.5 million, wide-row + $N_{90}P_{90}K_{90}$).

Thus, for the conditions of 2015, as the most stressful, the average ratio of inflorescence zones in oil radish was 16.9:61.1:22.0%, and for the conditions of 2014, as the most favorable in the formation of fruiting elements it was 26.4:62.0:11.9%. That is, optimization of the period of pod formation by improving the hydrothermal conditions contributes to a significant decrease in the proportion of fruits in the upper inflorescence zone with a similar increase in the proportion of its lower zone. We can trace this pattern in the context of all years of observations and gives grounds to adjust (for regions with different nature of the HTC indicator) the formation of reproductive effort of the oilseed radish plants with the selection of the most appropriate variant of pre-sowing construction of its agrocenoses. The interval grouping of the analyzed features of the pod is a confirmation of a certain zoning of the generative part according to the morphological features of the pod (Fig. 10, a; 10, b). Such an analysis, based on a pooled general population, makes it possible to analyze the overall dynamism of the distribution over the entire observation period. Such approaches proved to be successful in other similar studies as well (Weiner et al., 2009; Zając et al., 2011; Xiujuan, 2011; Vovchenko & Fursova, 2012; Tariq et al., 2020). However, in contrast to them, we used grouping by several morphological features of the pod and for different zones of the inflorescence.

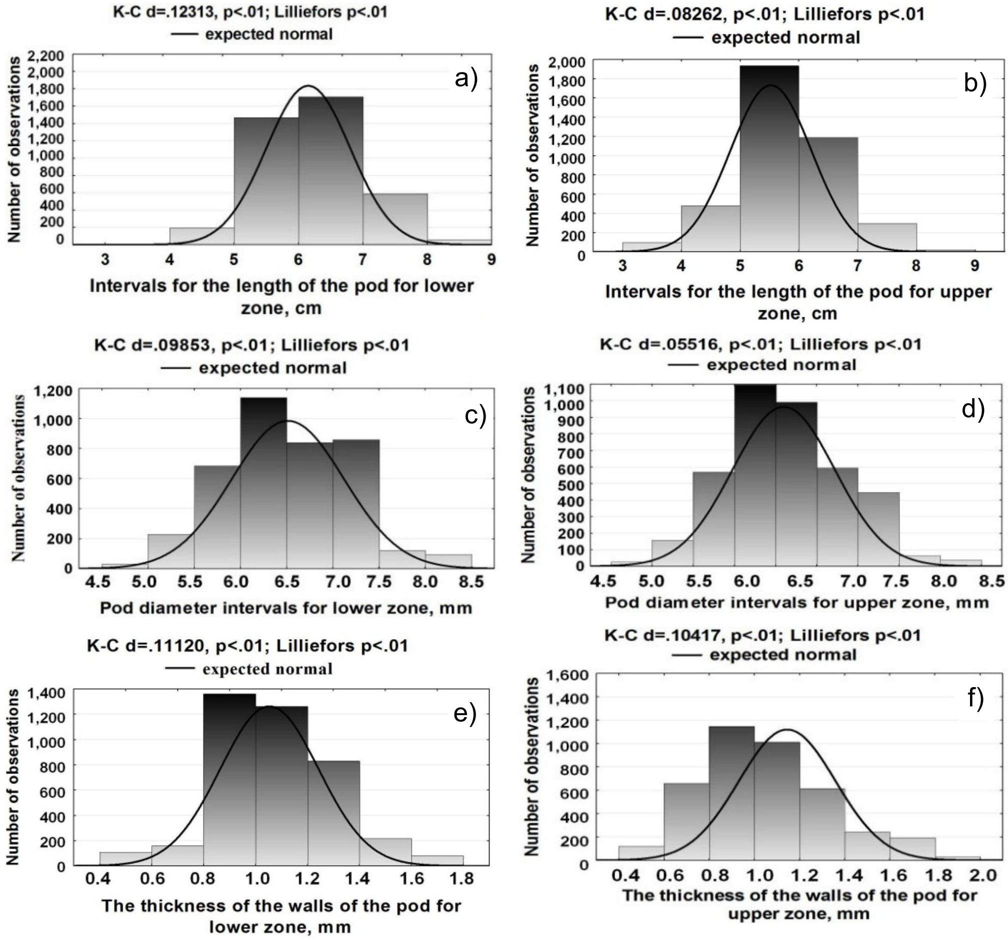


Figure 10, a. Distribution histogram of interval values of morphological features of oilseed radish pod in the section of the lower and upper zones of inflorescence at the rate of seeding 4.0 million pcs. ha^{-1} of germinable seeds on a variant without fertilizes (average of the three varieties for the general totality, 2013–2020).

This allowed to determine the peculiarities of the variation component of pod morphology within the general interval of each zone and additionally analyze the influence of technological options of pre-sowing design of the oilseed radish agrocenosis on the degree of variability of fruit elements. Thus, regarding the pod length at the sowing rate 4.0 million pcs. ha^{-1} of germinable seeds for the pods of the lower zone (Fig. 10, a (a–b)) we determined 5 intervals, and for the upper zone of the inflorescence we determined 6 intervals. Under the same conditions, pod length in the interval of 5–7 cm resulted in 86.8% of the considered pods in the lower inflorescence zone and 77.7% in the upper zone for an increase in the pod length interval of 4–5 cm from 3.3% for the lower inflorescence zone to 20% for the upper zone. When the density of oilseed radish agrocenosis decreases to 0.5 million pcs. ha of such seeds (Fig. 10 b, (a–b)), the total number of interval groups by pod length increases, and the dominant interval of 6–7 and 7–8 cm is 41.9% and 34.7% for the lower inflorescence zone, which is 25.2 and

30.9% less than for similar intervals of the upper inflorescence zone. According to the peculiarities of formation of pod diameter (Fig. 10 a, 10 b, (c–d)), similar patterns were determined in comparing the lower and upper zones: the variant of higher density of oilseed radish agrocenosis has a greater interval range of the indicator due to expansion of the lower limit of the range than the variant of 0.5 million pcs. ha^{-1} of germinable seeds. For the lower zone of the inflorescence, a significant increase in diameters above 6.0 mm for sowing rate of 4.0 million pcs. ha^{-1} of germinable seeds and above 8.0 mm for sowing rate of 0.5 million pcs. ha^{-1} of germinable seeds was established for both sowing rates. In particular, at the sowing rate of 0.5 million pcs. ha^{-1} of germinable seeds, the number of pods with a diameter of more than 8 mm was 35.9% for the lower zone and 12.7% for the upper zone.

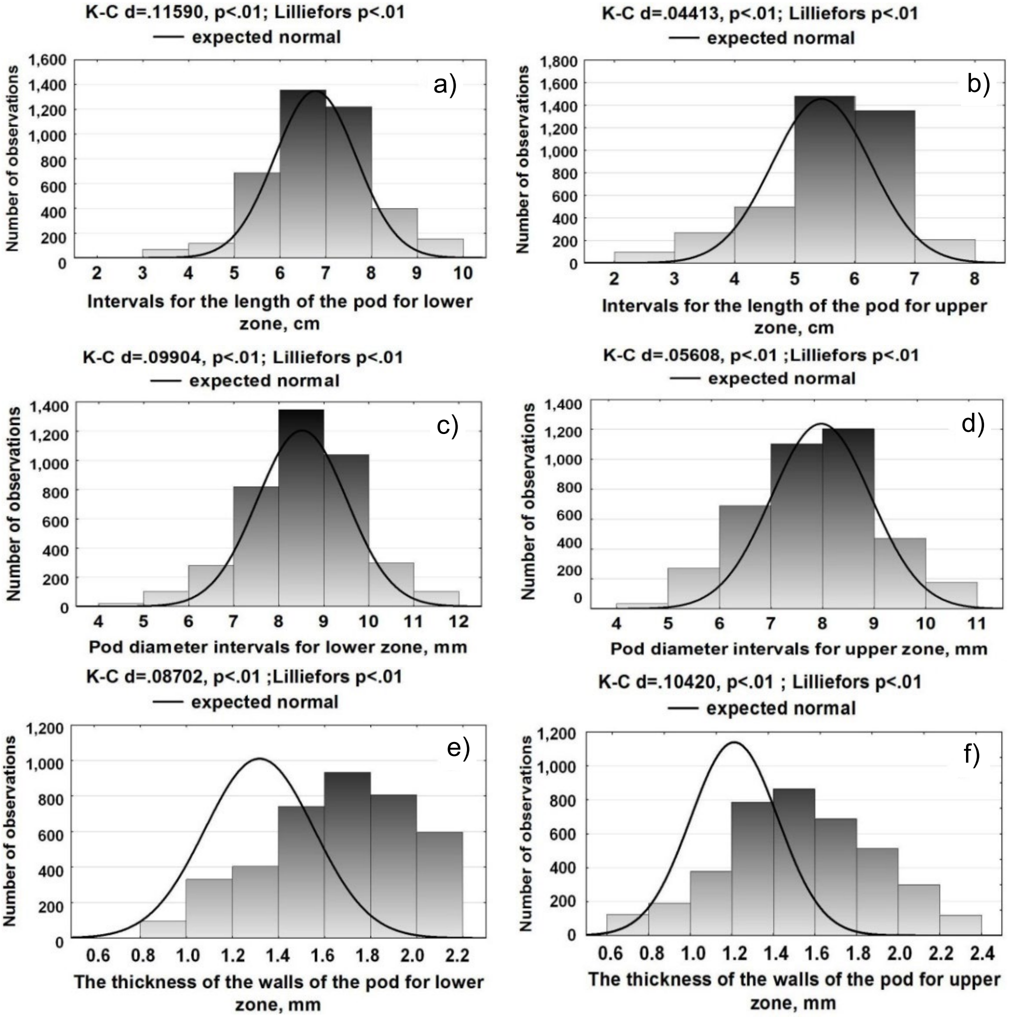
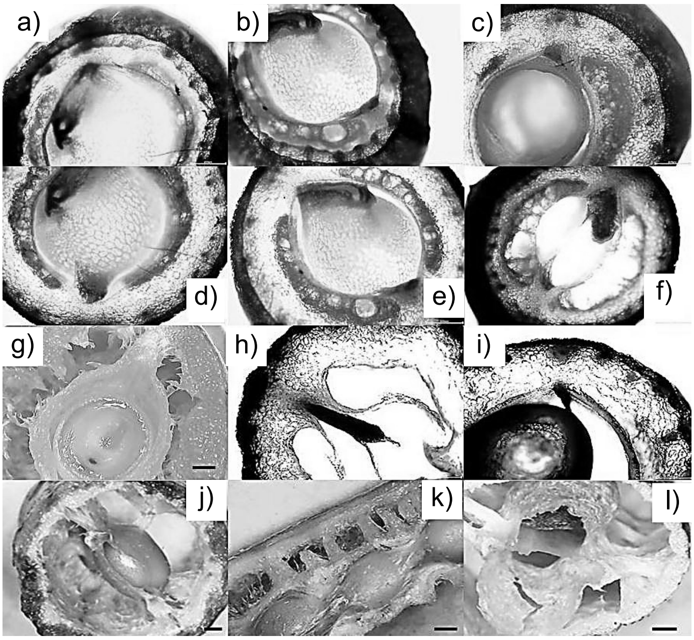


Figure 10, b. Distribution histogram of interval values of morphological features of oilseed radish pod in the section of the lower and upper zones of inflorescence at the rate of seeding 0.5 million pcs. ha^{-1} of germinable seeds on a variant without fertilizes (average of the three varieties for the general totality, 2013–2020).

We determined the specificity of pod wall thickness formation when its altitude tropation changes within the axes of inflorescence. In comparison with the lower zone, the index range increases with the appearance of limiting intervals, which were not considered. Thus, for the variant 4.0 million pcs. ha^{-1} of germinable seeds this interval range is 1.8–2.0 mm, and for the variant 0.5 million pcs. ha^{-1} of germinable seeds this interval range is 2.2–2.4 mm. At the same time, the change in the value of the interval for the upper zone has a greater amplitude of fluctuations within gradations, which confirms the earlier conclusions regarding the growth of morphological features of the pod in the direction from the base of the inflorescence axis to its apex. For the variant 0.5 million pcs. ha^{-1} of germinable seeds, a certain asymmetry in the value of filling intervals with a close indication in the interval of 1.6–2.0 mm is quite noticeable.

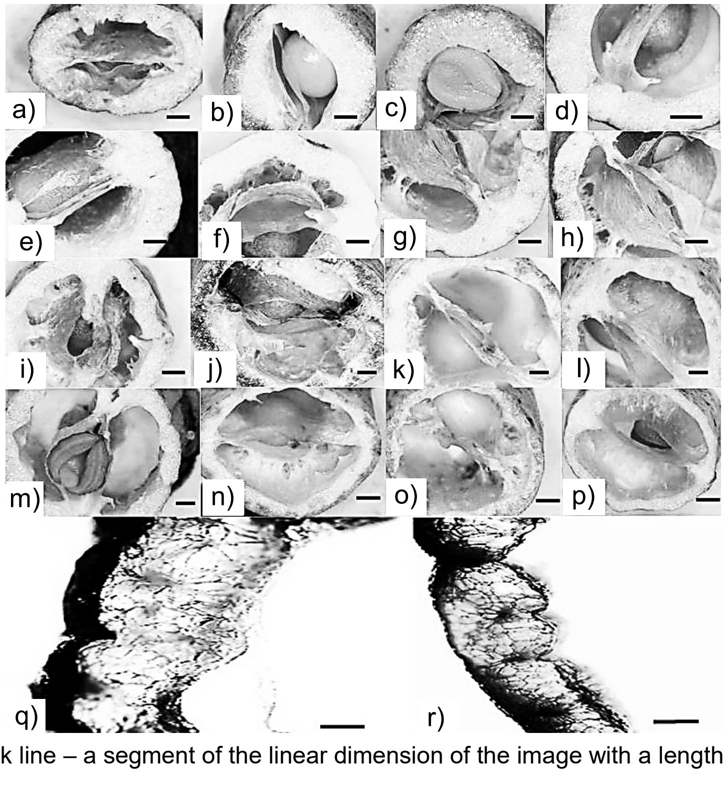


* the dimension scale line at the bottom of each image 1 mm long

Figure 11. Morphological stages of formation of the internal anatomical structure of the oilseed radish pod from the middle zone of the inflorescence (consistently: a – phenological stage BBCH 71; b – BBCH 73; c – BBCH 74; d, e – BBCH 75-76; f, g – BBCH 77-78; h–l – BBCH 77-85), 2020.

In our opinion, the appearance of pods with thicker walls in the upper inflorescence zone is determined by the peculiarities of pod formation stages and peculiarities of this process depending on pod placement in the inflorescences by height. In the initial stages of its formation, the endocarp is represented by parenchymal tissue adjacent to the seminal chamber (Fig. 11, a–b) (stage BBCH 69-71). Consecutively in the process of seed maturation, the filling parenchyma of the mesocarp is transformed with the formation of the space between the septum and the walls of the pod. It is formed a central longitudinal membrane of the pod, which creates a kind of capsule around the seeds, anatomically attached to the walls of the pod. At the same time the pods have a septum semitric to the seed chamber and a developed endocarpic multiple placental-type replum to the endocarp walls (Fig. 11, j–l) (stage BBCH 75-82).

According to Habekotté (1993), Bennett et al. (2011), Xiujuan (2011), Zhang et al. (2018) and Hasanuzzaman (2020) the nature of the formation of the internal anatomical structure of the oilseed radish pod guarantees protection against seed shedding and natural cracking of the pod walls. On the other hand, the staged transformation of the mesocarpic structure of the pod walls on the one hand is additional protection of seeds at the stage of its formation and maturation and on the other hand increases the dependence of the anatomical structure of the pod in the spatial structure of the inflorescence depending on environmental conditions. This has been emphasized in research Menendez et al. (2019). In our research this is confirmed both by the previously presented data of groupings (Fig. 10, a, b) and by microscopic study of the anatomical structure of the walls of the pods taken from different tiers of the inflorescence of oilseed radish. During the formation and maturation of seeds, the pod wall thickness, according to our surveys, was in the range 1.820–2.968 mm. During the microstage BBCH 76-83, the process of formation of the membranous sulcus with fetal seeds continues with a decrease in wall thickness to 1.156–1.698 mm. During the microstage BBCH 84-88, the wall thickness interval is set at 0.659–1.368. Under the same conditions, linear and radial growth of pods in different tiers of inflorescence differ (Fig. 12, q, r).



* indicator black line – a segment of the linear dimension of the image with a length of 1 mm.

Figure 12. Variation aspects of variants of pod wall thickness formation ((a–f) – pods of upper inflorescence zone with thickened walls; (g–k) – pods of middle inflorescence zone; (l–p) – pods of upper inflorescence zone with thin walls; q – cross section of the pod wall of the upper zone and r – cross section of the pod wall of the lower zone of the inflorescence at the phenological phase BBCH 87) in variant of sowing rate 0.5 million pcs. ha^{-1} of germinable seeds on a variant without fertilizers, 2020.

For the pods of the lower tier, which are formed first and accordingly to their morphological development in relation to the pods of the upper part shifted by 12–20 days, the rates of linear and radial growth are comparable in intensity. For the pods of the upper tier, due to the general weakening of physiological growth processes and a stage shift from the time of formation of the main part of the inflorescence, the specified growth rates are disproportionate.

CONCLUSIONS

Technological variants of pre-sowing construction of oilseed radish agrocenosis are determinative in the formation of pod morphometry and variability of its main linear and anatomical parameters due to changes in reproductive architectonics of plants, implementation of their compensatory ability and changes in the stages of flowering and spatial fruit formation. We proved that they provide the formation of morphologically different in the spatial structure of the generative part of the plant within each technological variant used in the study. Increasing the nutrition area with appropriate combinations of sowing rate and sowing method from 4.0 million pcs. ha^{-1} of germinable seeds to 0.5 million pcs. ha^{-1} of germinable seeds provides an overall increase in pod length by 38.5%, pod diameter by 60.4%, wall thickness by 92.5%. The application of additional mineral nutrition in the range from 30 to 90 kg ha^{-1} of the active substance provides an increase in these morphological parameters in comparison with the unfertilized control by 9.6–23.6% with a dominant positive effect on the level of general morphological development of plants and the formation of plants with intensive branching reproductive part. When reducing the nutrition area of oilseed radish, mineral fertilizers contribute to the range of variation of linear size of the pod on average in the studied variants in the range 12.5–24.7%. Variation of the nutrition area of oilseed radish plants determines the variability of morphological features of the pod within their vertical placement within the main axis and lateral branches of the inflorescence forming three distinct zones of such variability, namely, lower, middle and upper. The share of the middle zone for the studied technological variants was in the interval of 48.6–73.3% depending on the year of research, the lower was in the interval of 12.6–36.7%, the upper was in the interval of 6.9–23.9%. The growth of nutrition area and sowing method comparing the limiting technological variants 4.0 and 5.0 million pcs. ha^{-1} of germinable seeds provides, depending on hydrothermal conditions of pod formation period, an increase in the share of the upper zone by 4.1–6.7%, and the lower by 4.8–10.3%. At the same time, the nature of changes in pod length within the main axis and lateral branches has certain mathematical regularities of formation of a power function of the second order, most fully described by the equations in the Rational Function and Gaussian Model system. Determined features in the formation of pods depending on their altitudinal location in the direction from the base of the inflorescence axes to their apex and the system of grouping of morphometric parameters of oil radish pods within certain zones of variability allowed us to determine the patterns of formation of fruit elements in the spatial structure of the generative part of plants and compare their general morphological development with anatomical changes in the general pattern of microstages of pod formation, particularly pod wall thickness and the predicted effect of its ease of threshing for different inflorescence zones.

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