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Formation peculiarities of maternal variation of oilseed (fodder) radish pods

YAROSLAV TSYTSIURA[1]

The formation peculiarities of oil radish pods of different quality have been observed and scrutinized for many years, considering their tiered arrangement within the generative part of plants. Morphological features of an oilseed radish (*Raphanus sativus* L. var. *oleifera* Metzg.) pod are statistically grouped within the selected three inflorescence zones – lower, middle and upper. The paper specifies a peculiar range of values and variation of the basic morph qualities of a pod. The phasic pod formation is described in detail with regard to the features of its linear and radial growth, shaping peculiarities of the general internal anatomical structure. Regularities in forming different quality of oilseed radish pods in each selected area of the generative part are generalized and different technological approaches to agrophytocenosis modelling within the quite opposite technological approaches to such pattern are taken into consideration. Separate morph parameters of the oilseed radish harvest have been estimated in view of the adaptability of the collecting work and the potential loss of seeds.

Keywords: oilseed radish, *Raphanus sativus* var. *oleifera*, heterocarpy, inflorescence zone, layer, morphological features, morph qualities, variation

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INTRODUCTION

The variation in morphometric qualities of fruitage and seeds have resulted in the intensive processes of the generative development of a mother plant, peculiarities of the maternal variation in the intensity of fruit formation according to the flower position within inflorescence, which allow to predict the production nature in agrophytocenosis of a specimen, if combined with indicators of seeds viability (Bewley et al. 2013, Mitchell et al. 2017). Thereby, the study of fruit and seed formation regularities as a complex self-regulating system is relevant for new methods development of influencing a mother plant to provide effective regulation of forming the seeds, yielding and sowing qualities during the final stages of fruitage. On the other hand, fore-ordained by the nature and magnitude of fruit elements formation of a plant, individual seed productivity is determined by both the genetic heredity of an organism and the level of its modifying variability, which is stipulated by the changes of environmental factors, as well as agro-technological elements. Under these conditions, modification variation in a particular plant organism should be regarded within three basic species positions, i.e. ecological, maternal and genetic (Mitchell et al. 2017). Ecological variation should be considered as the result of interaction between a fruit and a seed, formed under certain environmental conditions. This variation type is not caused by genetics, but it is crucial in realizing the adaptive potential of forming the generative part of plants and providing appropriate levels of the reproductive effort (Biemond 2013, Van der Knaap & Ostergaard 2018). The fruit genetic diversity is closely connected to the same seed diversity and genetically determined, it is the result of realizing heredity of a plant organism. The general species type of heredity implementation (varietal characteristics) is preserved, although individual morphometric differences in the development of fruit and seeds appear because of the sexual process of their formation. The mutagenic factors can be the leading power of enhancing the genetic diversity. All types of variation can have both positive and negative genetic orientation. The maternal variation is referred to the morphological and anatomical variability of a fruit (the so-called heterocarpy) within a parent plant, stipulated by the position of a fruit itself in the spatial inflorescence structure and peculiarities of the morphological transformations tempos and their formation intensity in view of adetine and adaptive maternal effects (Langowski 2016). The key reasons for the maternal variation are differences connected with the placement of an individual fruit and seeds in different parts of the inflorescence according to the vertical and horizontal orientation, especially different flowering time, fertilization and formation of fruit elements, different intensity of plastic substances inflow during their formation due to re-utilization of their transformation from the vegetative part of a parent plant into fruits and seeds, as well as the different level of seed or fruit protection from the abiotic environmental factors (Labraa et al. 2017). The maternal variations are embodied in one of their versions: formation of agrophytocenosis layerage, realized in the spatial arrangement of lateral stems or branches related to the main peduncle, as well as in the formation of seeds and fruits in different zones of inflorescences in the same spatial aspect (Fu et al. 2016). The maternal variation of fruits as the biological and physiological aspect is significant in analysing the technology adaptability and optimality of the agrophytocenosis formation, regarding two standpoints: plant density per unit area and mineral nutrition. The maternal diversity becomes even more relevant in the system of the multi-level approach, including assessment of the zonal variation peculiarity of the generative part of plants, and the prominent features of the variability of pods proper in its different terminological meanings (Jacobs & Lesmeister 2012). The object of the current study belongs to cruciferous specimens; the features of heterocropy have been scrutinized in the range of studies according to the certain criteria (Xiujuan 2011, Langowski et al. 2016, Yang et al. 2016). Publications on the physiological and morphological features of the cruciferous specimens' formation are worth mentioning, since they represent the standpoints of anatomical factors and general morphological approaches, including the assessment of their abortion level and the reproductive effort (Li et al. 2019). It is emphasized on the high levels of variation in the morphological size of the cruciferous fruits and the layerage in the fruits' location. However, despite the scientific and theoretical relevance of the aspect of plant reproductive development, the issue of maternal fruit variation has been poorly covered, especially on crops that are marked by high probability of forming heteromorphometry within inflorescence due to their anatomical and physiological characteristics (Sablowski 2015, Hervieux et al. 2016). Oilseed radish should be attributed to such a specimen. Other aspects are also important. There is the estimation of the heterocarpy magnitude, differentiation of inflorescences by the morphological development of fruits, layerage in inflorescence and the morphoparameters of fruits, etc. An objective assessment is necessary for the issue of influence of the fruit variation level on the background of changing technological approaches to the construction of agrophytocenosis of cruciferous plants, including representatives of this family – an oilseed radish. That is why, estimation of the maternal variation level of the oilseed radish fruits will allow to determine the adaptation strategy of plants and to use this indicator as the one to optimize the formation of its agrophytocenosis. The object of research included an oilseed radish (*Raphanus sativus* L. var. *oleifera* Metzg.), identified as a cultivar of radish (*Raphanus sativus* L.), Genus *Raphanus* L., under the Tribe II *Raphanusae* DC, Tribe 5 Brassicaceae Hayek, and it belongs to the Family Brassicaceae, Order Capparidales, of the Class Dicotyledoneae. Multi-purpose study of oilseed radish in different soils and climatic zones made it possible to formulate the main positive features potentially inherent in this plant: unpretentious to the conditions of cultivation and precursor in crop rotation (Neubauer et al. 2014), highly productive and nutritious, productive in after-use and post-harvest use (Kruger et al. 2013), highly intensive functioning of the root system, relatively tolerant to changes in the sowing time, marked by rapid growth, with high positive reaction to mineral fertilizers, highly competitive in vegetation growing in grain fields, possibility of productive multi-component use within forage mixtures with a wide range of accompanying crops (Pearse et al. 2014), possibility of multi-purpose use (green mass, silage, haying, green manure, grass meal) (Teklu 2018), positive impact on the phytosanitary and nutrient regime of the soil, a good melliferous plant, and it is a means of revitalizing the fertility of depleted soils as a substitute for organic fertilizers by biomass ploughing (Pearse et al. 2014, Hu et al. 2018, Lewis et al. 2018), high nematode resistance (Vleugels et al. 2014, Teklu et al. 2014), high competitiveness against weeds (Brust et al. 2014, Kunz et al. 2016), use as feedstock for biofuel production (Chammoun et al. 2013, Ratanapariyanuch et al. 2013) and its honey productivity. The relevance of the study in the fruit variability aspects within inflorescences will optimize the process of field seed growing, connected with the formation of mechanized harvesting optimization, one-stage ripening of fruit elements and improvement of the pods threshing by ensuring the consistency of the latter according to the range of anatomical features and properties. It is also important to take into account the layer age features in flowering of different orders of inflorescences of the cruciform crops and, as a consequence, the corresponding stage in fruits formation from different layers in the vertical position of the latter from the inflorescence base to its apex. This causes well-known technological problems for the agrophytocenosis of the oilseed radish in the different periods of pod and seeds ripening, as well as in the choice of pre-harvesting plants preparation arising from the need for separate harvesting or the use of desiccation (Lang et al. 2016).

MATERIALS AND METHODS

Objects of the study included the cultivars of oilseed radish ‘Zhuravka’, ‘Raiduga’, and ‘Lybid’, which belong to the group of the main cultivars grown in Ukraine and distinguished by the combined use – for seed and forage purposes. The paper focused on the experimental data for ‘Zhuravka’ cultivar, since the obtained results and determined trends are similar in the formation of indicators during the growing season on the specified genotypes. The study embraced the formation peculiarities of the maternal variation indicators of oilseed radish cultivar ‘Zhuravka’ during changes in the technological parameters of its agrophytocenosis modelling, and it was conducted at the experimental field of Vinnytsia National Agrarian University on Luvic Greyic Phaeozem soils (for WRB classification) with medium-sized dry soil rotation during from 2013 to 2018: humus of 2.16-2.52%, pH of 5.8-6.7, easily hydrolysed nitrogen (N) intake of 71-77 mg/kg, mobile phosphorus (P_2O_5) of 187-251 mg/kg, and mobile potassium (K_2O) of 95–143 mg/kg. The study of the variability of the fodder radish pods was carried out with a scheme including extreme gradations of the technological spectrum of agrophytocenosis formation in the study area (Tsytsiura 2019), taking into consideration the borderline formats of the recommended mineral nutrition of the specimen (Table 1). The sowing period for all variants of research was between 8-12 April, determined by the conditions of the homotypic parameters of the soil workability and average daily temperatures (Table 2). In view of the vegetation conditions in 2013, there was a steady increase in average daily temperatures with a peak value at the level of 27-28°C under concentration of the depth of precipitation during May to the first ten-day period of June.

Table 1. The range of acceptable common options for the formation of oilseed radish agrophytocenosis in the study area.

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**	without fertilizers
2.0	1.0	$N_{30}P_{30}K_{30}$
3.0	1.5	$N_{60}P_{60}K_{60}$
4.0**	2.0	$N_{90}P_{90}K_{90}$

** underlined are variants for studying the variability of fodder radish pods.

Table 2. Precipitation and average daily temperature compared to the average over the study during the period formation of pods.

Months	Ten-day period of month	Years						Average long-term indicator (30-year averaging period)
		2013	2014	2015	2016	2017	2018	
Average daily temperature, °C								
May	III	15.3	19.5	18.2	17.4	17.1	19.0	15.3
	I	17.2	18.1	20.4	15.9	18.0	19.2	17.2
June	II	19.9	16.3	19.2	18.7	18.1	20.7	19.9
	III	20.8	15.7	18.2	23.7	21.4	17.9	20.8
July	I	19.7	19.2	21.5	19.3	18.2	18.6	19.7
Sum of precipitation, mm								
May	III	55.9	100.0	0.3	5.9	14.0	3.8	23.5
	I	36.0	43.1	3.2	15.0	1.8	0.5	22.8
June	II	71.0	0.0	28.8	38.9	11.9	91.3	24.7
	III	37.0	33.4	9.3	18.3	15.2	156.3	25.9
July	I	0.2	28.5	3.0	17.4	5.7	10.0	25.2

The conditions of 2014 were characterized by a temperature similar to that of 2013, with the cooler period of April-May. The depth of precipitation was relatively equal, especially during the period of the active vegetation of fodder radish in May and June. The intensive increase in average daily temperatures was observed in 2015 (maximum interval and steady high temperature background compared to the same period of other years) with the active atmospheric humidity in April–May and its minimum values in the summer period, which highlighted the specified year as the driest in the dynamics of years under consideration and stressful in relation to the agrophytocenosis development of different variants of oilseed radish. The weather conditions of 2016 resembled that of 2017, both years were characterized by average rates of increase in average daily temperatures against the remarkable rainfall intervals, with the more intensive depth of precipitation in 2016 in comparison with 2017. In addition, the temperature regime of the first period of April-May was cooler in 2017. Vegetation period of 2018 was marked as the coolest with the obvious humidity deficit during the period in April to the first ten-day period of June due to the shift of the amount of precipitation for the period of the third ten-day period of June to the second ten-day period of July, this interval distinguished this year of vegetation with extremely irregular rising temperatures in the period from sprouting to stemming of fodder radish to moderately stressful for a specimen. Typical of the plant under consideration, a long flowering and fruiting period was observed within all years of study, which according to the hydrothermal coefficient (GTC) level, was in the calendar interval – the third ten-day period of May and the first ten-day period of July. The favourable humidifying conditions in the spring period against the background of intensive temperature increase shifted the calendar start of plant flowering for at least one ten-day period. The flowering and fruiting duration depended on hydrothermal conditions of vegetation and ranged from 25 to 40 days, depending on the GTC of this period.

The evaluation of variation of the fruit morphological parameters was carried out due to selection of 125 pods in each repetition by the section of the selected inflorescence zones (a total corpus of 500 pods from each inflorescence zone). The total number of repetitions of each variant was 4. The plant analysis involved estimation of a group of 5 typical plants according to the length of the line stochastically along the width of the line with the displacement in a row horizontal starting from the beginning of plant flowering [BBCH 62 (Test guidelines…2017)] up to the phase when all the pods reached a cultivar of types (BBCH 86). The indicated plants were marked by colored markers with appropriate numbers for dynamic assessment of the intensity of linear and lateral growth of a pod. Analysis of the pods morphology was performed within the selected generalized typical inflorescence zones taking into account such features as the length of a pod (LP, cm), the diameter of the pod (D, mm), and the thickness of the pod walls (TW, mm). The electronic sliding calipers Digital Caliper (precision measurement of 0.01 mm), and the thickness gauge with the digital Fiber indication (measurement accuracy of 0.01 mm) were used to determine these morphometric features. The microscopic examination of sections of the pod implied the implementation of USB microscopy method with the use of Sigeta MCMOS 5100 5.1 MP USB 2.0 (in combination with a digital microscope for 10× and 40× optical zoom formats). Measurements and observations were accompanied by field and laboratory photography using Canon EOS 750D Kit with the objective lenses Canon EF 100 mm 2.8L USM. The general methodology of the research, the account of phenological phases (BBCH scale) in the system of features of the fruiting phase of oilseed radish and other related observations and records were carried out in accordance with the basic recommendations of studies with cruciferous crops (Sayko 2011) and methodological descriptive guidelines of classification rating tables (Test guidelines… 2017). Data were processed using standard methods of variational statistics, using a package of statistical application programs SPSS, Statistica and Excel.

The level of variation of morphological features and grouped indicators was conducted according to coefficient of variation (CV): very low (CV <7%); low (CV=8-12%); average (CV=13-20%); increased (CV=21-30%); high (CV=31-40%), and very high (CV> 40%).

RESULTS AND DISCUSSION

It was found that variability of the morphometric parameters of oilseed radish pods is determined by the fact that its generative organs are ontogenetically heterogeneous, since they are formed on sprouts of different branching orders and at different times, getting into different environmental conditions. Their development is equally ensured by moisture, minerals and photosynthesis products This causes a prolonged flowering that lasts for over a month (Table 2) for oilseed radish, and it results in significant heterocarpy (genetically determined formation of different generative rudiments on a flowering plant) within the inflorescence, which is reflected in the seed productivity of the plants themselves. This is primarily connected to the peculiarities of the inflorescence formation due to the elongation of its main axis and the gradual formation of new flowers in the direction from the base of the peduncle to its apex, which is traced on both the main inflorescence axis and its lateral branches and inflorescences of lateral sprouts. In addition, the presented features of forming the inflorescence spatial structure predetermine a long period of fruit formation and seed ripening, a significant difference in the time of the pod formation and duration of seed filling according to its position in the inflorescence: lower fruit elements have a corresponding longer formation period, as a consequence, higher index of the morphological development than the fruit elements of the middle layer, and the upper, in particular. The visibility of such fruit formation is manifested already on the stages of the initial formation of fodder radish fruits and is gradually completed by varying degrees of heterocarpy within different orders of inflorescence (Figure 1).

In these features, oilseed radish differs from other cruciferous. Thus, for rapeseed (Yeasmin et al. 2014) and white mustard (Jat et al. 2018), the level within the inflorescence is less pronounced. These cultivars had a less prolonged flowering period of 7-12 days and less intensive branching of the inflorescence (axes 2-5 orders).

For the account of the above-mentioned arguments at different stages of flower and pod formation, the hierarchical structure of the oilseed radish inflorescence has the corresponding layerage features, which are expressed both in the difference in the stage of pod and seed formation, and in the morphological parameters of the last gradations from the base of the inflorescence to its apex. Even during the brown pod phase (BBCH 83-86), the presence of flowers on the apical part of the generative part of the fodder radish plants is marked. Similar peculiarities have been observed in general for the genus *Raphanus* L. (Luo et al. 2018). However, in our studies, we found that the divergence in the formation of pods was displaced by 5-8 units of the BBCH scale. These are significantly different stages of fruit formation in oilseed radish from other cruciferous plants. In conclusion, the features above result in the

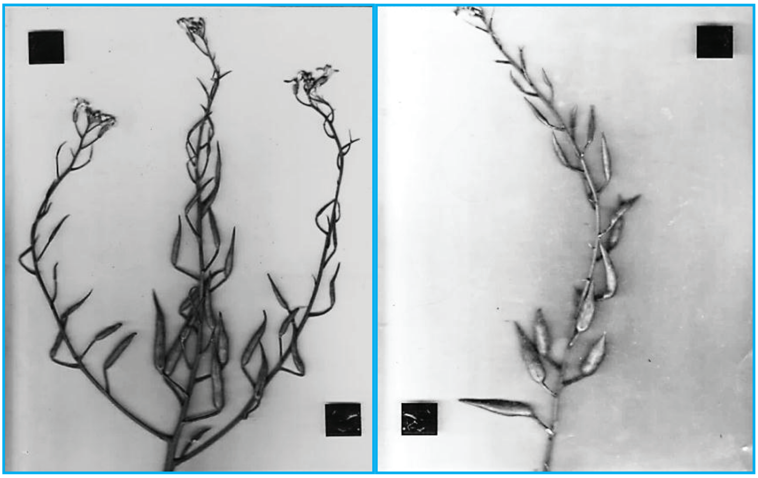


Figure 1. Layerage in the formation of fruit elements of oilseed radish cultivar 'Zhuravka' with a prominent gradient from the inflorescence base to its apex in the direction of growth of the peduncles axes, 2018. Legend: dimension of the black square is 2 × 2 cm.

formation of a dynamic row of fodder radish pods within the inflorescence axes (Figure 2).

In view of these features, there are clearly distinguished zones within the inflorescence of oilseed radish, starting with the phenological phase of a green pod (micro stage BBCH 71): zones with fully formed pods in length and diameter, areas where the pods are morphologically in the active morphological growth and become closer to completely formed pods by size, and zones where pods have only reached half of the morphological expression of the characteristic cultivar, or start to form actively. Gradually, in the process of ripening of oilseed radish plants on the phase of the yellow pod (microstage BBCH 76-78), the formation of pods of the middle and especially the upper zone continues, but due to general physiological changes their intensity was generally lower than the formation of pods of the lower zone, which belong to the primary.

This peculiarity in the gradients of growth and formation of pods in oilseed radish has been noted for winter rapeseed (Anđelić et al. 2018) and explains the peculiarities of the formation of cruciform inflorescences presented in several studies (Pospišil et al. 2014, Vinze et al. 2017). The proportion of each zone of inflorescence of oil radish was established in accordance with the morphological development of pods and was varied depending on the characteristics of the vegetation of plants in terms of hydrothermal regime (Table 3).

The value of shares of the relevant areas of the inflorescence had a different character of the formation depends on hydrothermal conditions of the growing season. At the seeding rate of 4.0 million units ha^{-1} of germinating seeds minimum share of the inflorescence zone and the maximum percentage of the upper zone

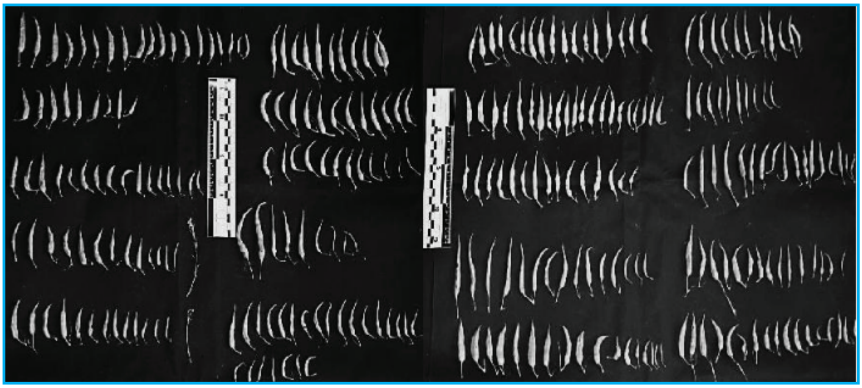


Figure 2. Morphometric row of oilseed radish cultivar ‘Zhuravka’ pods at the micro stage BBCH 73 sequentially for each row from the base of inflorescence branches to the apex within lateral branches for four plants, 2018. Legend: Left position – for seeding rates of 4.0 million units ha^{-1} of similar seeds on the fertilized background $N_{90}P_{90}K_{90}$; Right position – for sowing rates of 0.5 million units ha^{-1} of similar seeds against the fertilizer $N_{90}P_{90}K_{90}$.

Table 3. Percentage of zones of inflorescence of oil radish cultivar ‘Zhuravka’ by morphological development of pods per phase of a brown pod (BBCH 86-89) for different technological variants, averaging 2013-2018 (% of the total inflorescence length).

Years of research	Hydro-thermal coefficients for vege-tation	Proportions of zone in the total length of inflorescence, %					
		Lower zone	Middle zone	Upper zone	Lower zone	Middle zone	Upper zone
		Seeding rate of 4.0 million units·ha^{-1} without fertilizers			Seeding rate of 4.0 million units·ha^{-1} on the background $N_{90}P_{90}K_{90}$		
2013	1.527	26.3±1.7*	65.1±2.8	8.6±1.1	23.8±1.9	69.3±3.3	6.9±1.4
2014	1.269	24.2±1.8	65.3±2.7	10.5±0.9	20.6±2.1	70.7±3.3	8.7±1.2
2015	0.430	14.2±2.7	66.7±4.6	19.1±1.9	12.6±3.1	71.6±5.3	15.8±2.2
2016	0.663	18.5±1.9	69.1±3.1	12.4±1.2	16.5±2.4	72.6±4.0	10.9±1.6
2017	0.824	18.9±1.5	69.7±2.9	11.4±1.4	16.8±1.8	73.3±3.3	9.9±1.5
2018	1.179	21.3±2.1	68.5±2.9	10.2±0.8	19.8±2.3	71.9±3.7	8.3±1.4
$LSD_{0.05\ (for\ year)}$		1.51	1.34	1.82	1.59	1.27	1.96
Years of research	Hydro-thermal coefficients for vege-tation	Seeding rate of 0.5 million units·ha^{-1} without fertilizers			Seeding rate of 0.5 million units·ha^{-1} on the background $N_{90}P_{90}K_{90}$		
2013	1.527	33.8±2.2	54.5±3.7	10.7±1.5	36.7±2.5	50.7±4.6	12.6±2.1
2014	1.269	28.8±2.4	58.5±3.8	12.7±1.4	31.9±2.8	53.6±6.5	15.5±3.7
2015	0.430	18.9±3.5	56.6±5.7	24.5±2.2	21.8±4.2	49.5±9.4	28.7±5.2
2016	0.663	21.6±2.5	60.6±3.9	16.8±1.4	24.3±3.8	56.0±6.3	19.7±2.5
2017	0.824	23.1±2.0	62.0±3.8	14.9±1.8	26.9±3.4	57.4±6.1	16.7±2.7
2018	1.179	25.5±2.7	61.2±4.2	13.3±1.5	27.7±4.3	56.4±7.4	15.9±3.1
$LSD_{0.05\ (for\ year)}$		1.23	1.19	1.14	1.38	1.29	1.09

* arithmetic mean error for $p \leq 0.05$

was established for conditions in 2015 with a minimum value of hydrothermal coefficient (GTC) of 0.430. The maximum proportion of the lower zone and the minimum share of the top areas were established for the conditions of 2013 with a maximum value of hydrothermal factor of 1.527. That is, stressful conditions which affected the total number of pods and their morphological development for cruciferous crops, as noted in several studies (Annisa et al. 2013, Parvaiz 2017, Kirkegaard et al. 2018) were decisive in the formation of matricule variability of pods of the oilseed radish. Fertilizer for this seeding rate provided an overall increase in the share of the middle zone of the inflorescence 3.5-4.2% depending on the year of study with a maximum value of a gain for high GTC. In the variant seeding rate of 0.5 million units ha^{-1} of germinating seeds without fertilizers, the nature of the influence of hydrothermal features of the year was similar to the variant of seeding rate of 4.0 million units ha^{-1} of germinating seeds. However, the overall differentiation of the inflorescence into zones maternal variability of pods was higher for all the study years. Thus, the average index of growth of the share of the lower zone to match the options of 4.0 and 0.5 million units ha^{-1} of germinating seeds amounted to 1.23. For the upper zone, the rate was 1.29. For the middle zone, on the contrary, the reduction index was 0.87.

Mineral fertilizers ensured the growth matricule variability pods. The corresponding indexes for areas inflorescences were 1.54, 1.80, 0.75. The interaction of the minimal cenosis pressure at the minimum seeding rate, and maximum doses of fertilizer ensured the growth of the total variability in the morphology of the pods of the oilseed radish. The growth of intensity in these conditions, the growth processes contribute to the formation of different growth gradients for the pods at the base and in apical part of inflorescence axes.

The statistical analysis of the morphological characteristics of the radish pods on the layers from the inflorescence base to its apex (including lateral branches of the main axis) consistently resulted in specification of the levels of their variation within each zone (Table 4). The interval distribution of the morphological features of ‘Zhuravka’ pods was also determined in the correlation between the lower and upper inflorescence zones for seeding rates of 4.0 million units ha^{-1} of similar seeds and 0.5 million units ha^{-1} of similar seeds (Figure 3) on unfertilized backgrounds.

The presented results enable us to make conclusion about the layerage heterocarpy in fodder radish, which causes the differentiation of pods by the basic parameters of the morphological development as in the variants of the highest technologically applied density of its agrophytocenosis in 4.0 million units ha^{-1} of similar seeds and in the variants of the maximum allowable technological liquefaction at the sowing rate of 0.5 million units ha^{-1} of similar seeds. The most variable feature was the thickness of the pod walls in its middle zone with a range of 0.41 to 1.49 mm, which corresponds to the average gradation of 18-20% variation. The variability of the diameter in a pod was the lowest with the variation index within the scrutinized options of 9.34-14.5%. The following regularities should be singled out in evaluating the morphometry of the features formation by inflorescence layers in the direction from the base to the top: reduction of the pod length by changing its shape in the interval of 15.8-24.6% in comparison with the top layer to the lower, reduction of the pod diameter in the interval of 6.5-11.8% matching the upper to the lower layer, increasing the thickness of the pod walls in its middle part by 8.3-9.6% for the same level of correlation. According to the established levels of heterocarpy, oilseed radish can be attributed to plants with significant heterocarpy within the inflorescence. For other representatives of the cruciferous family, this index was one gradation lower in the value of the coefficient of variation (Yang et al. 2017).

Table 4. Statistical evaluation of the index variability of the morphological development of oilseed radish cultivar 'Zhuravka' pods per phase of a brown pod (BBCH 86-89) within reproductive areas (average for 2013-2018 for the annual sample n = 500 for the general observation set N = 3,000).

Zones of generative part	Length of pod (LP), cm		Diameter of pod (D), mm		Thickness of walls of pod (TW), mm	
	CV, %	$X_{mid.}$, cm	CV, %	$X_{mid.}$, mm	CV, %	$X_{mid.}$, mm
Seeding rate of 4.0 million units ha^{-1} of similar seeds without mineral fertilizers						
Lower	10.61	6.15±1.28*	9.34	6.51±1.19	18.01	1,05±0,25
Middle	11.15	5.98a±1.31	10.19	6.41b±1.28	18.12	1,08c±0.26
Upper	12.52	5.12a±1.36	10.20	6.10a±1.22	18.68	1,14b±0.28
Seeding rate of 4.0 million units ha^{-1} of similar seeds on the background $N_{90}P_{90}K_{90}$						
Lower	11.16	6.69±1.42	10.08	6.76±1.34	18.34	1,10±0.27
Middle	11.63	6.20a±1.41	10.88	6.52a±1.39	18.88	1,11±0.27
Upper	12.97	5.45a±1.51	10.85	6.23a±1.38	19.42	1,22b±0.29
Seeding rate of 0.5 million units ha^{-1} of similar seeds without the mineral fertilizers						
Lower	13.11	6.77±1.74	11.67	8.52±1.95	17.34	1,19±0.28
Middle	13.45	6.58b±1.73	11.97	8.38b±1.97	17.62	1,25b±0.29
Upper	15.08	6.05a±1.61	13.54	7.57a±1.90	18.29	1.34a±0.31
Seeding rate of 0.5 million units ha^{-1} of similar seeds on the background $N_{90}P_{90}K_{90}$						
Lower	14.41	7.41±2.01	13.25	8.85±2.30	18.85	1.25±0.31
Middle	14.90	6.88a±1.98	13.56	8.53a±2.27	19.04	1.29b±0.31
Upper	15.91	6.37a±1.99	14.50	8.04a±2.24	19.42	1.37a±0.34

*arithmetic mean error for a ≤ 0.05. Levels of significance of the middle and upper zone data in comparison with the lower: a – 0.1%, b –1%, c – 5%. CV – coefficient of variation, $X_{mid.}$ – average value.

It was also found that the use of mineral fertilizers contributed to the intensification of heterocarpy in oilseed radish due to the growth of both the linear dimensions of a pod and the interval of indicators' values. This has been confirmed in studies by analogy with other cruciferous cultivars (Szczepaniak et al. 2014, Baskin et al. 2014).

The maximum effect of fertilizers in terms of pod variation was observed precisely in the cenosis variants of lower density. Cenosis with the maximum plant density due to the cenotic pressure demonstrated lower variability of morph parameters according to the variation coefficient and the substantiality of pod morphological differences within the inflorescence was less marked. This corresponds to the established effects of the change in the density of agrophytocenosis on the morphological expression of plant features in cruciforms (Nasiri et al. 2017).

It should be highlighted that the use of an unfertilized background allows to reduce the variability in morphological features formation and the corresponding substantiality of the pods morph analysis. The presented data of the plants interval

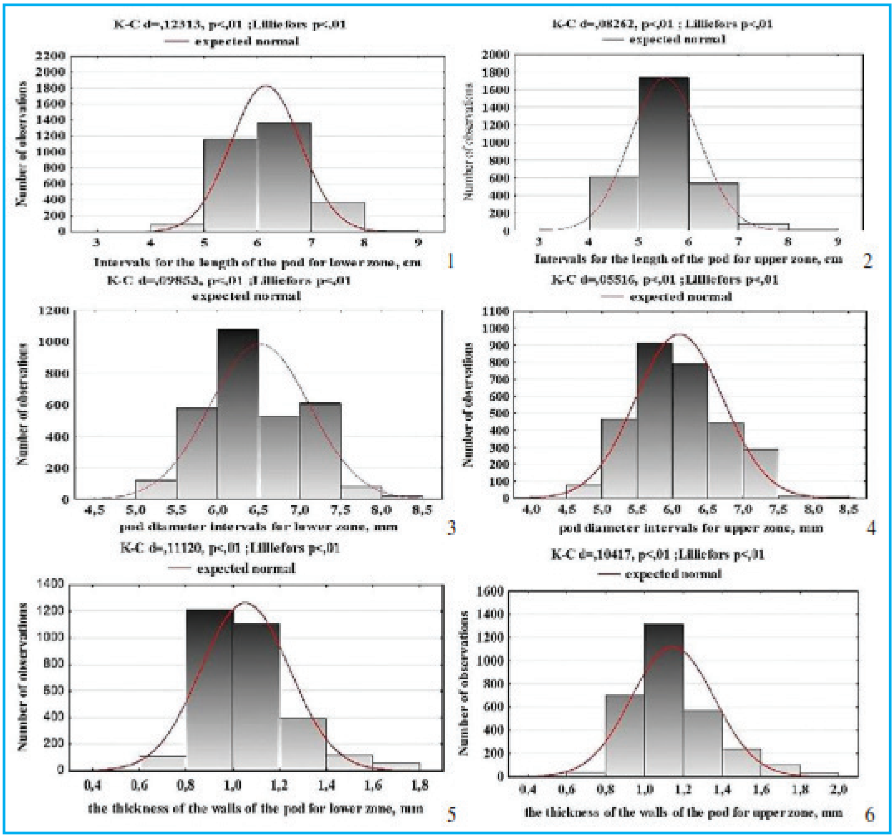
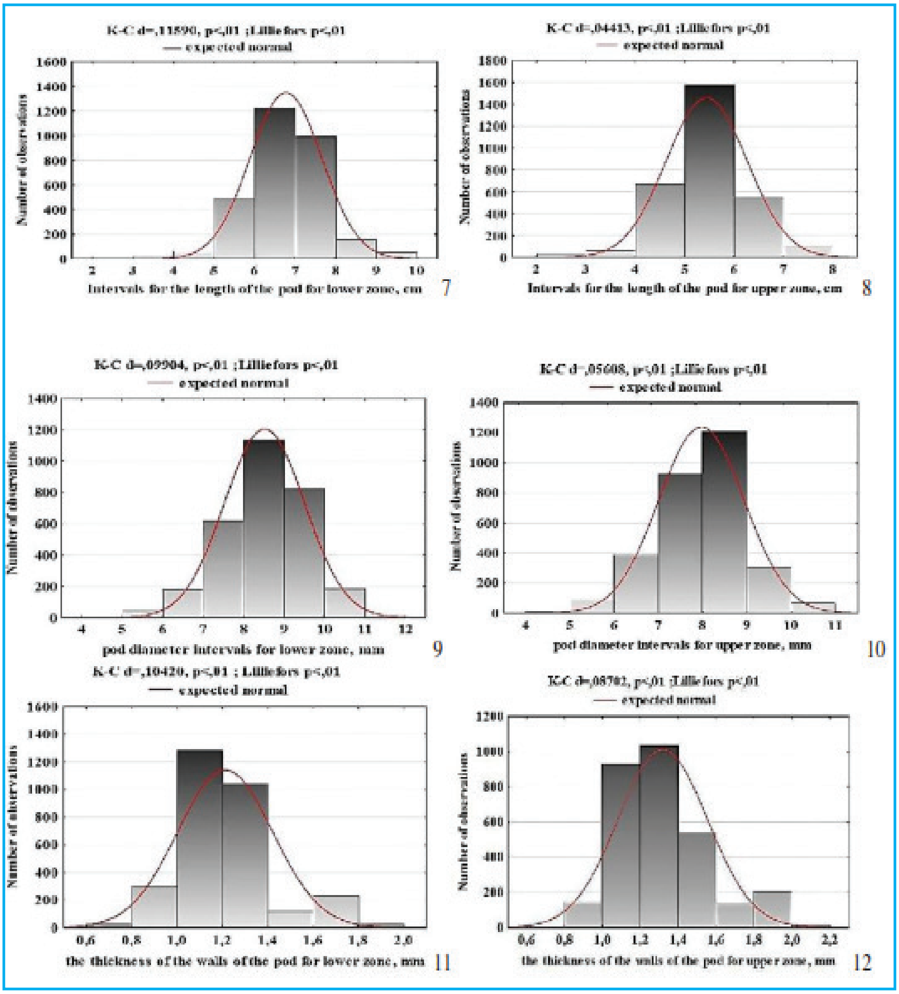


Figure 3. Histogram of the interval values distribution of morphological characteristics for the oilseed radish cultivar 'Zhuravka' in the section of the lower and upper inflorescence zones for seeding rates of 4.0 million (positions 1-6, see above) and for seeding rates of 0.5 million units ha^{-1} of similar seeds (positions 7-12, see opposite page) on a non-fertilized background in total for the period of 2013-2018.

distribution have been obtained from the consolidated general corpus, which allowed to analyse the overall dynamics of distribution over the entire study period.

The five intervals for pods of the lower zone are defined in terms of the pod length at the seeding rate of 4.0 million units ha^{-1} of similar seeds (Figure 3, positions 1-2), and six intervals – for the upper inflorescence zone. Under the same conditions, 86% of the recorded pods in the lower inflorescence zone had the length of pods in the interval of 5-7 cm, and 77.7% – in the upper zone by the pods length increase of 4-5 cm with 3.3% for the lower inflorescence zone and up to 20% – for the upper. Since the density of oilseed radish agrophytocenosis dropped to 0.5 million units ha^{-1} of similar seeds (Figure 3, positions 7-8), the total number of interval groups increases by the pod length, and the dominant interval of 6-7 and 7-8 cm for the lower inflorescence zone stands for 40.7 and 33.3%, which was



24.7 and 30% less than for the same intervals of the upper inflorescence zone. According to the diameter pod indicators (Figure 3, positions 3-4 and 9-10), similar patterns were determined in the comparison between the lower and upper zones: a smaller interval of the index value was specified for the variant of oilseed radish with the higher density agrocenosis, which remained identical to the variant 0.5 million units ha^{-1} of similar seeds with the same number of interval groups. Both seeding rates for the lower inflorescence zone have been established and distinguished by a significant growth in diameters: above 7 mm for a seeding rate of 4.0 million units ha^{-1} of similar seeds and above 8 mm for a seeding rate of 0.5 million units ha^{-1} of similar seeds. For the former seeding rate in particular, the number of pods with diameters higher than 8 mm was 34.0% for the lower zone and 11.6% for the upper during the analysed period. Thickening of the pod by the growth of its placement in height, which is confirmed by the data of Table 3, as well as by almost double growth of the number of pods with a thickness from 1.6 to 2.2 mm (Figure 3, positions 5-6 and 11-12), which were combined to its anatomical formation stage, with certain peculiarities for fodder radish (Figure 4). Such peculiarities of formation of anatomical structure of pods of different tiers were not noticed for any representative from the cruciferous family except oilseed radish.

Some observations on the possible anatomical variability of the walls of pods in rapeseed's inflorescence and other cruciforms are revealed by the studies of Cavalieri et al. (2014) and Gulden et al. (2017). Thus, the core of the fodder radish pod in the initial stages of its formation was a completely filled parenchymal tissue (in succession from left to right 1 and 2 positions) (stage BBCH 69-71). The maceration of the filling parenchyma occurred diametrically, with the formation of a central longitudinal septum of the fetus, at the stage BBCH 74-75 (positions 3 and 4) during the active seed formation and the pod growth. This maceration created a kind of a capsule around the seeds, anatomically attached to the fruit walls. According to our assessment findings, the thickness of the pod walls varied from 1.820 to 2.968 mm. During the micro stage BBCH 76-81 (positions 5 and 6) forming the membranous core with fruit seeds continued with the reduction of wall thickness to 1.156-1.698 mm. During the microstage BBCH 84-88 the wall thickness interval was in range of 0.659-1.368. The linear and radial growth of pods differed in different layers of inflorescences under the same conditions. Tempos of the linear and radial growth were comparable in intensity for the pods of the lower layer, which were gradually formed by the first and, accordingly, their morphological development was displaced by 12-20 days related to the pods of the upper part. The specified growth rates were disproportionate for the pods of the upper layer due to the general weakening of the physiological growth processes and the stage shift

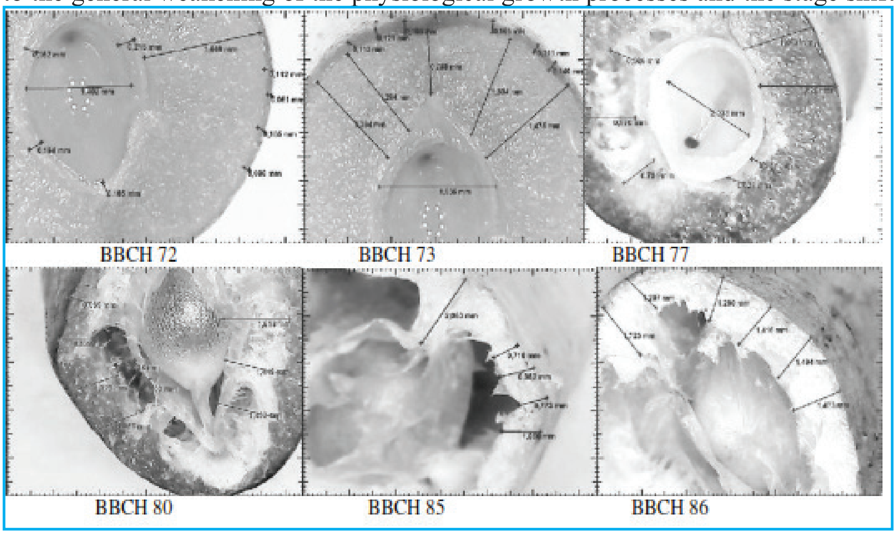


Figure 4. Formation stage of a fodder radish pod in cross section, 2016. (magnification 100-200x)

from the formation terms of the main part of inflorescence.

For this reason, it was observed that a general thickening of the walls within the upper layer pods at their smaller length and diameter, accordingly, and a less marked seed chamber with a vertical section of a fruit. The upper layer pods under the analysed period had been distinguished by the presence of pods with anomalously thickened walls at the borderline calculation date, and fruits of different walls thicknesses of the carpels were noticed (Figure 5).

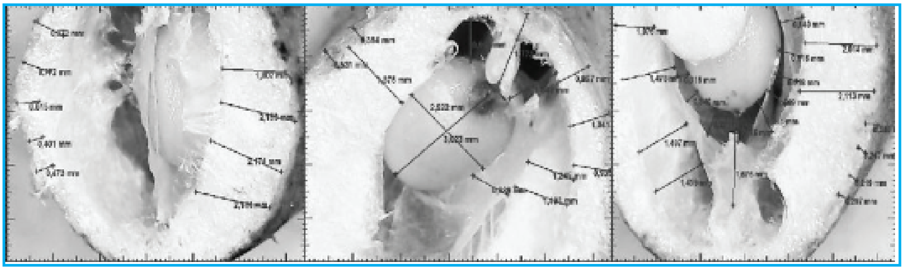


Figure 5. Asymmetric pods of the upper layer according to the thickness of walls (magnification 100–200x, right and left asymmetry of the thickness of the pod's walls), 2018. (*All images on micro stage BBCH 86)

From the viewpoint of threshing easiness that means that the pods of the upper layer of the inflorescence will have the most mechanically strong walls and heavy seeds threshing out. This feature is important to ensure the quality of the harvest and to substantially reduce its loss in all, without exception, cruciferous crops (Zhang et al. 2012, Azadbakht et al. 2013). For these reasons, the differentiation level of inflorescences of oilseed radish plants both, in the layer of its main axis and in the lateral branches of the lateral reproductive character, will determine the harvesting efficiency to the certain extent and the level of seed loss.

Carefully selected parameter of sowing rate should be introduced in view of the factor that we have been studying – heterocarpy, taking into consideration the formation peculiarities of the feature of the pod walls thickness in the layer of two radically different technological options for the agrophytocenosis modelling of radish oil in 4.0 and 0.5 million units ha^{-1} of similar seeds, namely: lower levels of fruit morphology variation and less marked layerage of fruit elements under denser agrocenosis from the position of seed growing. Hydrothermal vegetation conditions, as in the case of the formation of a part of the inflorescence zone due to the maternal variability of the pods, influenced their morphological parameters (Figure 6). This effect was different for different zones of the inflorescence. The formation of morphological features of the pods in the lower zone by the value of the correlation coefficient and the regression equation had a lower level of determination (R^2) relative to the value of the hydrothermal coefficient (GTC) (Figure 6). This type of dependence was noted for both the variant with the highest density of agrophytocenosis of oilseed radish (4.0 million units ha^{-1} of similar seeds) and the lowest (0.5 million units ha^{-1} of similar seeds). However, the bond strength

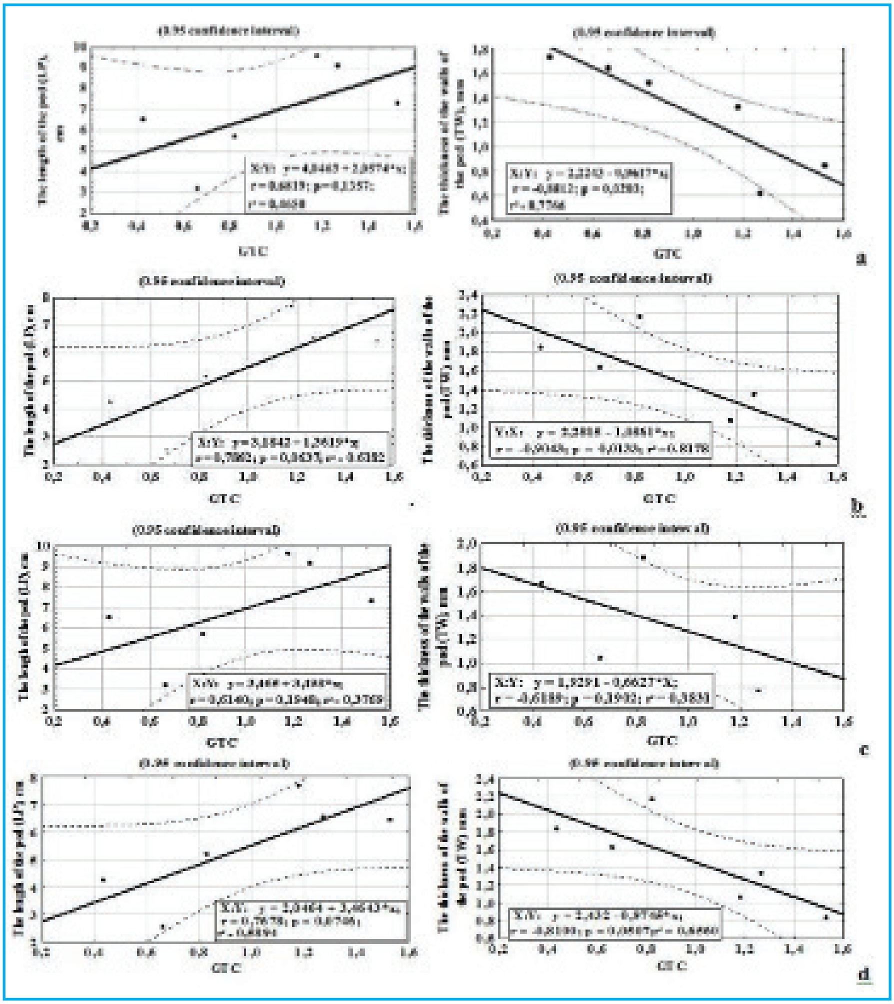


Figure 6. Relationship between the hydrothermal coefficient of the vegetation period of the oilseed radish (GTC) and the length of the pod (LP, cm) and the thickness of the pod walls (TW, mm) for different inflorescence zones, averaging 2013-2018. Legend: position a – lower zone and b – upper zone for variant 4.0 million units ha^{-1} of similar seeds without fertilizer application; position c – lower zone and d – upper zone for variant 0.5 million units ha^{-1} of similar seeds without fertilizer application.

averaged over the assessment period was higher for both zones at the maximum coenosis density.

The influence of hydrothermal conditions, which for cruciferous crops in the early stages of vegetation influences the formation of future generative structure (Parvaiz 2017) in the formation of maternal variability of pods had a combinatorial interaction with the level of coenotic pressure of agrophytocenosis. This is clearly corroborated by the presented graphs and equations of dependencies performed for variants without mineral fertilizers, which corresponds to the methodology of studying correlation-regression dependencies in the system of application of agrochemicals. Similar features of the formation of pods against the background of changing weather conditions had been observed for other cruciferous cultures (Weymann et al. 2015).

CONCLUSION

It was found that the formation of pronounced heterocarpy in a narrow meaning, which implies formation of pods of different size in the direction from the base to the apex of the inflorescence is characteristic of oilseed radish. The effect of heterocarpy involved a reduction in the length of the pod, its diameter and an increase in the thickness of the pod walls, which differentiated the inflorescence of the oilseed radish into three zones: lower, middle and upper. The materiality of this effect becomes the most obvious within the green pod microstage (BBCH 71-73). Technological parameters of construction of agrophytocenosis of oil radish have influence on the value of heterocarpy. On average, during the brown pod microstage (BBCH 86-89) for the two most distant technological variants of the formation of agrophytocenoses reduction of the length of pods of the upper zone compared to the pods of the lower zone was 16.75% on the background without fertilizer and 18.54% on the background $N_{90}P_{90}K_{90}$ for the variant of 4.0 million units ha^{-1} of similar seeds. The same indicators for the variant 0.5 million units ha^{-1} of similar seeds were 10.64 and 14.04%. The decrease in the diameter of the pod for the same options was 6.30, 7.84, 11.15 and 9.15%. The increase in the thickness of the pod walls for the same variants was noted 8.57, 10.91, 12.61 and 9.60%, which indicates an increase in the mechanical strength of the pods of the upper zone. It was found that the increase in average daily temperatures against the background of the decrease in rainfall during the growing season of oilseed radish formed higher levels of inflorescence zones due to the maternal variability of pods. The effect of weather conditions from the point of view of the growth of the maternal variability of the pods was maximum in the variant of the minimum density of coenosis of 0.5 million units ha^{-1} of similar seeds with the corresponding growth index in the range 1.23-1.29 for the lower and upper inflorescence zones while reducing the size of the middle zone with a decrease ratio of 0.87 to a seeding rate of 4.0 million units ha^{-1} of similar seeds. It is noted that the growing stress of vegetation due to the decrease in GTC provides a general decrease in the linear size of the pods as the thickness of their walls increases. The magnitude of these changes is maximal for the upper inflorescence zone on the basis of the maternal variation.

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