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Matrix quality variability of oilseed radish (*Raphanus sativus* L. var. *oleiformis* Pers.) and features of its formation in technologically different construction of its agrophytocenosis

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Abstract. Overview of the formation of matrix variability of oilseed radish seeds at two levels: within a single pod and within the generative part of the plant, given the presence of vertical layering in the placement of fruit elements. The peculiarities of formation of variation component of morphological parameters of seeds from different zones of inflorescence were estimated, basing on their electrical scanning for oilseed radish agrophytoconosises of different technological construction and sowing rate against the background of four options of mineral nutrition (without fertilizer to the level 90 kg ha^{-1} with an equal interval of 30 kg ha^{-1} of the primary material). The results of the value of matrix variability in morphological and weight characteristics were grounded on the basis of the analysis of the structure of selected seed fractions and their intra-group variation. The main features of formation of morphometric variability of seeds from different zones of inflorescence depending on different technological construction were formulated.

Key words: heterospermy, matrix variability, morphological parameters of seeds, oilseed radish, seed fractions, separation variability.

INTRODUCTION

Modern approaches to seed production technologies provide for the transition from general concepts of qualitative categories of seeds in general to the study of complex patterns of its formation. This provides prediction of its yield, sowing and adaptive properties and allows obtaining seeds with a high level of genetic (matrix), ecological-adaphic and morphological uniformity. Seed uniformity in this aspect is considered as a factor in ensuring optimal and uniform germination rates, which forms a high-intensity agrophytocenosis of the culture with the same standing density, the desired level of coenotic stress and feeding conditions (Scarisbrick, 1982; Wulff, 1986; Bouttier & Morgan 1992; Aicher, 2011; Balodis & Gaile, 2016; Stankowski et al., 2019; Wilczewski et al., 2020).

Heterospermia of seeds is considered as its difference in morphological characteristics, biochemical composition and physiological state, the ability to germinate and certain provide productivity of plants in offspring (Venable, 1985; Geritz et al., 1999; Alonso-Blanco et al., 2009; Li et al., 2014, 2014a; Yang et al., 2017).

Scientific practice distinguishes three types of heterospermy, namely ecological, matrix and genetic (genotypic) (Kizilova, 1974; Makrushin, 1994; Zhu & Weir, 1994; Yizhyk, 2000, 2000a; Rahman & Vetty, 2011; Hua et al., 2012). Ecological quality variability is the result of interaction of seeds in the process of its formation with environmental factors and belongs to not hereditary form, but it is an important aspect of the formation of biological and morphological properties of seeds and levels of seed productivity in the format of implementation of the genotype-environment combination (Leishman, 1995; Rees, 1996; Zhu, 1996; Fox et al., 1997; Nikolayeva, 1999; Imbert, 2002; Yang & Midmore, 2005; Gunasekera, 2006; Silveira et al., 2012; Sadras et al., 2013; Zhang et al., 2013; Ivanova & Sarmosova, 2014; Gnan et al., 2014; Yang et al., 2017; Li et al., 2020).

Genotypic variability is the result of a combination of hereditary signs of parental forms. In these conditions, while preserving the general type of heredity (varietal characteristics), each seed has differences due to the insemination process. This type of variability is also caused by mutagenic factors (Tayo & Morgan, 1978; Clarke, 1979; Morgan, 1980; Kindruk, 1990; Smith & Scarisbrick, 1990; Batygina, 1999; Ali et al., 2002; Wolfe & Mazer, 2005; Kaushik et al., 2007; Kennedy et al., 2011; Würschum et al., 2012; Li et al., 2014; Fu et al., 2015; Li & Li, 2015a; Li et al., 2015b; Li et al., 2019).

Matrix variability is one of the most common options and is formed as a result of different placement of flowers within the inflorescence on the mother plant. As a result, conditions are created for different nutrition conditions of different inflorescence levels and different influence of the plant as a mother body. Even if genetic and environmental factors are identical, the location of the seeds leads to the heterospermy detection (Olsson, 1960; Cavers & Steel, 1984; Inanaga & Kumura, 1987; Roach & Wulff, 1987; Smith & Scarisbrick, 1990; Habekotté, 1996; Makrushin, 1994; Donohue & Schmitt, 1998; Mazer & Wolfe, 1998; Nikolayeva, 1999; Sundaresan, 2005; Sadeghietal., 2011; Bukharov & Baleev, 2012; Hua et al., 2012; Zhang et al., 2016: Zheng et al., 2017).

The primary reasons for the matrix variability are the differences associated with the placement of individual seeds in different parts of the inflorescence in the vertical and horizontal orientation, namely: different flowering time, insemination and seed formation, different input intensity of plastic substances in the process of seed formation due to the reutilization of their transformation from the vegetative part of the mother plant fruits and seeds, as well as different degree of protection of the seedor fruit from abiotic environmental factors (Tayo & Morgan, 1978; McGregor, 1981; Roach & Wulff, 1987; Chay & Thurling, 1989; Kindruk, 1990, Makrushin, 1994; Donohue & Schmitt, 1998; Lemontey et al., 2000; Zlobin, 2009; Faraji, 2010; Kennedy et al., 2011; Wang et al., 2011; Gomez & Miralles, 2011; Gnan et al., 2014; Khan et al., 2014; Xing et al., 2014; Yang et al., 2016, 2017). This changes the physical and mechanical, chemical, sowing and yield properties of seeds. For these reasons, the creation of a control system for matrix heterospermia is a more important prerequisite for obtaining high-quality seed (Berry & Spink, 2006; Faraji, 2012; Monty et al., 2016).

As biological and physiological aspects, the matrix quality variability of seeds is important in the analysis of adaptability of technology and optimality of formation of agrophytocenosis both from the position of plant density in the unit area and from the position of mineral nutrition (Tsytsiura, 2019). For the group of cruciferous crops, among which is the object of our study, the signs of heterocarpy and heterospermy were studied by separate indicators in a number of studies. Thus, the results of the study of peculiarities of flowering stages of the generative part of rapeseed (McGregor, 1981; Habekotté, 1996.) and mustard (Vovchenko & Fursova, 2012) were made public. The peculiarities of forming the spatial structure of winter and spring rapeseed are highlighted (Tayo & Morgan, 1978; Smith & Scarisbrick, 1990; Habekotté, 1996). Issues of modeling the architectonics of rapeseed inflorescence and estimation of peculiarities of fruits and seeds uniformity within the inflorescence in such modeling are considered (Wang et al., 2011; Li et al., 2016). The influence of fractional composition of seeds of a number of cruciferous crops on the consistent formation of its sowing and yielding qualities was grounded (Olsson, 1960; Nikolaeva et al., 1999, Vyshnivsky, 2014). The evaluation of the general stage of flowering period of individual cruciferous crops and their influence on the formation of conditioned seeds was carried out (Smith & Scarisbrick, 1990; Polowick & Sawhney, 1986).

It is also noted for many cruciferous crops that the degree of variability of seeds is determined by the level of mineral nutrition of plants (Gattelmacher et al., 1994; Ozturk, 2010; Béreš et al., 2019), as well as technological factors such as the nature of the combination of fertilizer (Vujaković et al., 2014), the relationship between macro and micronutrients in the fertilizer system (Jankowski et al., 2014). In the formation of morphological features of seed development within the inflorescence a significant influence on this indicator of the technological features of nitrogen nutrition. In terms of flowering duration, the nature of flower formation, the use of phosphorus fertilizers and trace elements, as well as their ratio (Gomez & Miralles, 2011; Grant et al., 2013; Ragab et al., 2015; Sieling et al., 2017; Béreš et al., 2019; Zou et al., 2020).

The area of plant nutrition in the agrocoenosis due to the regulation of the value stress in turn determines the morphological development of plants, reproductive effort and seed productivity. The increase in standing density per unit area is directly proportional to the decrease in the generative part of plants with a decrease in the reaction rate interval in terms of morphological and weight characteristics of fruits and seeds (Hocking & Stapper, 2001; Takashima et al., 2013). As a result, the morphometric and weight alignment of seeds for many cruciferous crops, including oilseed radish, will be determined by the optimal ratio of technological parameters of subsowing formation of agrocenosis at the appropriate value of background mineral nutrition (Rathke et al., 2005; Al-Doori & Hasan, 2010; Qian et al., 2012; Sieling et al., 2017; Porter et al., 2020). For each plant species, these parameters are individual and rather extent unique (Berry et al., 2010; Qian et al., 2012). On the other hand, this conditions are different for different soil-climatic zones, but tend to be similar (Hocking et al., 1997; Horst et al., 2003; Marjanovi´c-Jeromel et al., 2011). It is also noted that considering the aspects of the matrix variability of seeds, given its fractional composition during harvesting and separation, provides a reduction of yield losses up to 30–39% and significantly improves the homogeneity of seed material and provides optimization of growth processes for agrophytocenosises basing on its consistent reproductive use (Makrushin, 1994; Kyrpa, 2011).

On the other hand, it was noted (Hasanuzzaman, 2020) that despite the agro-technological value of a number of crops from the cruciferous family. These factors are studied in detail on winter and spring rape and little-studied on white and black mustard, spring colza, and the object of our study oilseed radish as well.

For this group of crops, which also includes oilseed radish (*Raphanus sativus* var. *oleifera* Pers.), in addition to the above types of seed variability within its matrix type, its individual subtypes are distinguished: gravimorphic (differences in seed weight, size, shape, pattern) and enantiomorphic (differences in symmetry and asymmetry of a seed or fruit) (Dorofeyev, 2004; Tsytsiura & Tsytsiura, 2015). A number of questions remain to be discussed concerning the estimation of the general level of variation of morphological parameters of seeds in cruciferous crops and their influence on the value of realization of individual seed productivity of plants. It is also important to consider the peculiarities of layering in the flowering of different orders of the inflorescence of cruciferous crops (Schiessl et al., 2015) and, as a consequence, the corresponding stage in the formation of fruits from different tiers in the vertical placement of the last from the base of the inflorescence to its apex. This feature is noted by a number of researchers on winter and spring rapeseed (McGregor, 1981; Scarisbrick et al., 1982; Habekotté, 1996; Wang et al., 2011; Vyshnivsky & Slisarchuk, 2014) but is poorly studied on oilseed radish plants. This leads to well-known technological problems in the time diversity of seed maturation and choice of pre-harvest preparation of plants, associated with the need for separate harvesting or the use of desiccation, the latter has certain limitations in the application for the oilseed radish agrophytocenosises (Tsytsiura, 2018a). Given the above facts, the assessment of the level of matrix variability of oilseed radish varieties will make it possible to determine the adaptation strategy of plants, and use this parameter as an indicator of the optimization of agrophytocenosis formation.

MATERIALS AND METHODS

The research on the formation of indicators of the matrix variability of oilseed radish varieties of plants with changes in technological parameters of the construction of its agrophytocenosises was carried out during 2013–2018 on the experimental field of theVinnytsia National Agrarian University (N 49°11′31″, E 28°22′16″) on dark gray forest soils (Luvic Greyic Phaeozem soils (Working Group WRB, 2015)) of the medium loam mechanical compositi on with fluctuating basic agrochemical indicators in the rotation section: humus content 2.16–2.52%, pH 5.8–6.7, lightly hydrolyzed nitrogen content 71–77 mg kg^{-1}, mobile phosphorus 187–251 mg kg^{-1}, exchangeable potassium 95–143 mg kg^{-1}. The basic technological scheme of technological construction of oilseed radish agrophytocenosises provided for the application of the interval of technological solutions adopted in the region in terms of row width and sowing rate in

Table 1. The range of acceptable common options for the formation of oilseed radish agrophytocenosis in the study area (Tsytsiura, 2019)

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)	Without fertilizers
1.0	0.5	$N_{30}P_{30}K_{30}$
2.0	1.0	$N_{60}P_{60}K_{60}$
3.0	1.5	$N_{90}P_{90}K_{90}$
4.0	2.0	

accordance with zonal recommendations of oilseed radish cultivation in the zone of theforest-steppe of moderately continental belt (Table 1). Term of sowing of all variants corresponded to the period of the end of the first-middle of the second ten-days period of April.

Three recognized varieties of oilseed radish, namely, 'Zhuravka', 'Raiduha' and 'Lybid', were used in the research. These varieties belong to the varieties of combined use for fodder purposes and seeds with wide adaptive potential for cultivation in different soil and climatic zones.

The hydrothermal regime of oilseed radish vegetation during the period of seed formation and filling differed (Table 2).

Table 2. Precipitation amount and average daily temperature in comparison with the long-time average annual regime for the research period

Months	Ten-days period	Years						Long-time average annual value (30-year averaging period)
		2013	2014	2015	2016	2017	2018	
		Average daily temperature, °C						
	I	17.2	18.1	20.4	15.9	18.0	19.2	15.9
June	II	19.9	16.3	19.2	18.7	18.1	20.7	16.7
	III	20.8	15.7	18.2	23.7	21.4	17.9	17.5
	I	19.7	19.2	21.5	19.3	18.2	18.6	18.2
July	II	18.6	19.7	19.0	20.6	19.2	19.1	18.8
	III	18.6	21.3	22.7	21.6	21.7	21.5	19.0
Average for the selected period, °C		19.5	18.5	19.7	20.8	19.8	19.1	17.7
		Precipitation amount, mm						
	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
	I	0.2	28.5	3.0	17.4	5.7	10.0	25.2
July	II	11.1	39.0	11.9	44.0	18.6	44.0	23.8
	III	15.4	15.0	5.8	6.7	67.7	52.3	29.2
Amount forthe selected period, mm		134.7	216.8	56.2	125.3	119.1	302.1	151.6
		HTC**						
May		1.305	2.783	0.719	1.227	0.645	0.258	1.460
June		2.202	1.078	0.613	0.893	0.349	3.124	1.416
July		0.377	1.137	0.230	0.682	0.806	1.349	1.396
August		1.047	0.750	0.061	0.486	0.563	0.349	1.234
Average for the vegetation period		1.232	1.437	0.406	0.822	0.591	1.270	1.377

* – grey color marks the period from flowering (BBCH 63) to the yellow-brown pod phase (BBCH 86) of the oilseed radish for phenological conditions of the study area; ** $HTC = \frac{\sum R}{0.1 \cdot \sum t_{>10}}$, where the amount of precipitation (ΣR) in mm over a period with temperatures above 10 °C, the sum of effective temperatures ($\sum t_{>10}$) over the same period, decreased by a factor of 10 (Polyovy & Bozhko, 2007).

Variation of morphological parameters of seeds was estimated with a sample of 25 plants in non-contiguous repetitions (total sample of 50 plants). Total number of repetitions for each variant 4. Plant analysis provided for the evaluation of a group of 5 plants in 5 places by the length of the line stochastically by the width of the area with a displacement in the line horizontal to the phase of brown maturity of the pod BBCH 87 (Hocking, 1997; Meier, 2001; Skinner & Moore, 2007) when all the pods have reached a typical size.The formed seeds were selected separately from the three zones of the oilseed radish inflorescence (evenly with the same interval on the total height for each inflorescence according to the general recommendations for determining the vertical level and mosaic of agrophytocenosises (Rabotnov, 1992)). Peculiarities of oilseed radish fruit anatomy due to the evaluation of heterospermy level were carried out taking into account scientific developments in the field of carpology for cruciferous crops (Puri, 1941; Zohary, 1948; Levina, 1987; Lotova & Rudko, 1999; Dorofeyev, 2004; Ilyinska, 2013.

Seed mass characteristics were determined with the use of laboratory scales RADWAG PS 1000.R1with 0.001 g discretion.Analysis of fractional composition of seeds was carried out by sifting the selected average sample of seeds on testing sieve sets with a round cell according to Specifications 23.2.2068-94 typeIandwitha rectangular cell according to Specifications 5.897–11722–95, TC 23.2.2068-94 type II. The fractional composition was also determined by the method of processing a single-layer scanned image of seeds using the Digimizer image analysis software package (v 4.2). Weight of 1000 seeds was determined according to the state national standard (State standard of Ukraine 4138-2002, 2003).

Seed parameters were estimated based on such characteristics as projection surface area (PS, mm^2), surface perimeter (P, mm), seed length (L, mm), seed width (W, mm), roundness (R, mm), seed sorting index (SI) (ratio of seed length (L, mm) to its width (W, mm)).

Study of the morphological structure of fruits was conducted in accordance with the general recommendations of morphological and anatomical analysis of cruciferous fruits (Puri, 1941; Zohary, 1948; Levina, 1987; Lotova & Rudko, 1999; Dorofeyev, 2004; Ilyinska, 2013).

To determine these morphometric characteristics, used Didital Caliper (measurement accuracy of 0.01 mm), USB microscopy SigetaMCMOS 5100 5.1 MPUSB 2.0 (in combination with a digital microscope for ×10 and ×40 optical magnification formats) and OotdtyDM–1600, 2 MP with corresponding software and using ImageJ 1.52 software.

The matrix variability index (MVI) in comparison with the morphological parameters of seeds from the lower and upper inflorescence zone was determined in relation to the average coefficient of variation (CV,%). Measurements and observations were performed using field and laboratory photography with the camera Canon EOS 750DKit and lenses Canon EF 100 mmf/2.8 LUS Mand CanonMP-E 65 mmf/2.8 1-5 x Macro.

General methodology of researches, consideration of phenological phases in the system of signs of oilseed radish bearing phase and other related observations and records were conducted in accordance with the basic recommendations of researches on cruciferous crops (Sayko, 2011; Test Guidelines…, 2017) using the package of statistical software Statistica 10, Exel 2013, Past 324 and biometric methods of statistics

(Zar, 1984). The level of variability of morphological features and grouped indicators was conducted on the scale (Zaytsev, 1984): very low (CV < 7%); low (CV = 8–12%); medium (CV = 13–20%); elevated (CV = 21–30%); high (CV = 31–40%); very high (CV > 40%). Given the massiveness of the data and general similarity in the values of formation of features for the studied oilseed radish varieties. The data are presented by key indicators for 'Zhuravka' variety.

RESULTS AND DISCUSSION

According to our preliminary estimates (Tsytsiura, 2018b), there is a great variation in the seeds of oilseed radish varieties. The seed of this crop itself has a number of morphological forms, which, in average, make it possible to attribute it to the egg-shaped one with different index of length to width ratio. This is clearly demonstrated in Fig. 1.

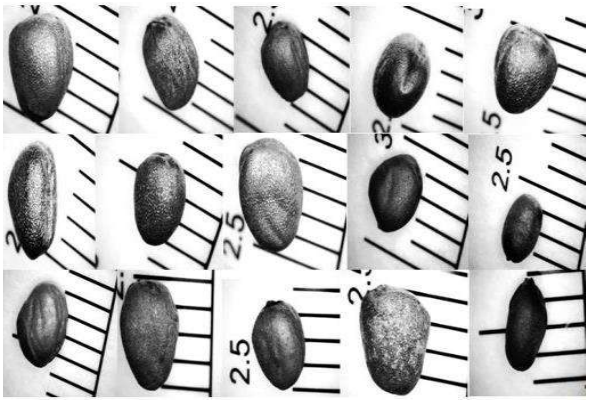


Figure 1. Quality variability of oilseed radish seeds of the 'Zhuravka' variety by typological linear sizes and shape, 2015.

According to the presented typological forms of seeds there are egg-shaped, elongated egg-shaped, flattened egg-shaped, oval, globe-shaped and various combined forms. Seed color is also a variable indicator (gravimorphic variability) from grey and brown to dark brown with a dark red shade. The color tends to change from light brown for newly harvested seeds to brownish red for seeds after long-term storage. Common external morphological features can be identified for any oilseed radish seed of any shape (Fig. 2). The seed is divided into two symmetrically cotyledonary lobes, separated by a shallow hollow of hypocotyl and coleorhiza elements. These elements are most noticeable on seeds of the middle zone of the pod. The formation of seeds of different sizes within the pod for oilseed radish is determined by several reasons. Some of them are associated with the peculiarities of the formation of different morphotypes of pods in the context of different zones of inflorescence, determined by a certain layering of formation of fruit elements the gradient of height (Tsytsiura & Tsytsiura, 2015; Tsytsiura, 2018, 2019). Depending on the tier (lower, middle and upper) (Fig. 3) the oilseed radish pods differ in length, diameter and their ratioas well as by the wall thickness of the pod itself. In particular, the pods of the upper zone in comparison with the pods of the lower zone have thicker walls, significantly shorter length of the pod

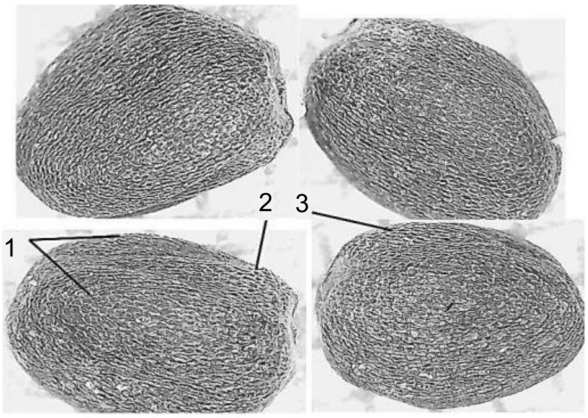


Figure 2. General appearance of oilseed radish seeds of the 'Zhuravka' variety from different positions, 2018.

itself and overall higher variability in its morphology. The staging of the phenological formation of pods of the upper zone also has signs of desynchronization in the format of accelerated formation and maturation. It causes to deformation of the fruit walls, and to the appearance of such morphotypes as twisted, spiral, crescent, etc.

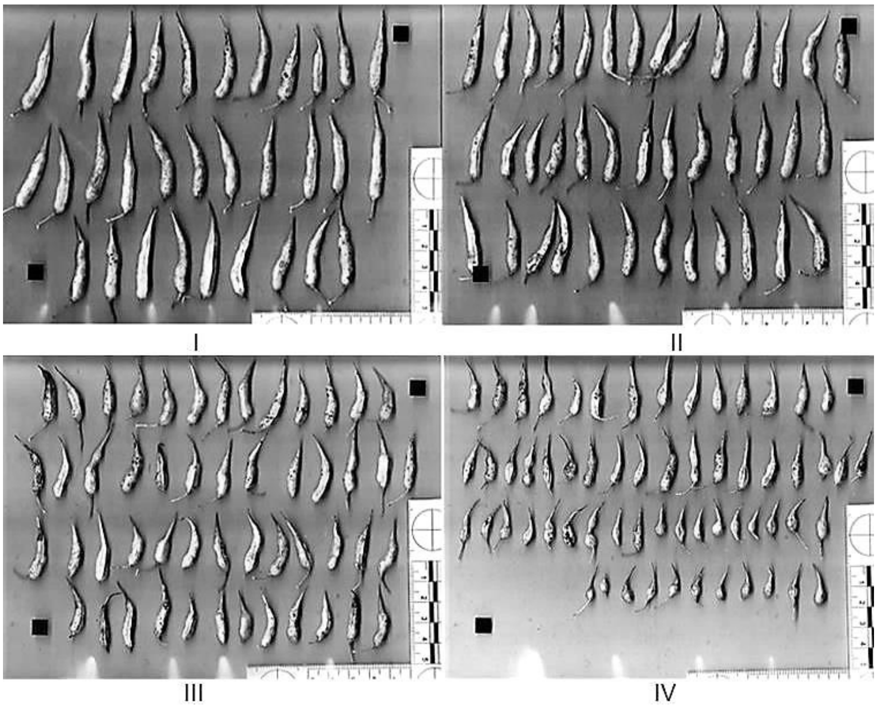


Figure 3. Morphotypes of oil seed radish pods of the 'Zhuravka' variety (I – pods of the lower zone; II – pods of the middlezone; III, IV – pods of the upper zone) for thetechnological variant of 2.0 mlnpcs. ha^{-1} of the germinable seeds with wide-row sowing against the back ground $N_{90}P_{90}K_{90}$ (for the phenological phase BBCH 87–88) (black square with dimensions 2×2 cm), 2018.

This nature of change in the morphology of the fruit provides not only a general decrease in the number of seeds in the pod in the direction from the base to the apex of the inflorescence at the oil radish. This is the scope of variation in the shape and size of the seed and its individual weight characteristics. Such features of pod formation for oilseed radish create prerequisites for reducing the favorability of the formation of the seed itself. This eventually leads to a change in the shape of the seed itself. Similar features were noted on a number of agricultural crops, including those of the cruciferous family (Levina, 1987; Pechan, 1988; Bouttier & Morgan, 1992; Mazer & Wolfe, 1998; Faraji, 2010, Hua et al., 2012; Gnan et al., 2014; Li et al., 2014, Li & Li, 2015a; Li et al., 2015b; Yang et al., 2016, Li et al., 2019, 2020).

The matrix variability of seeds in oilseeded radish pods within one inflorescence zone is also due to the peculiarities of its formation from the earliest stages after successful insemination. Conducted anatomical and microscopic studies at the stage of initiation of the formation of oilseed radish pods (BBCH 68-71), which indicate marked differences both in the size of the seed at the beginning of its formation and in the staging of its development. With these features, the format of the matrix variability by the height placement factor of a seed in a pod can be defined as differently directed. Over the period of many years of observations, I have found a gradual decrease in linear sizes of seeds from the base of the pod to its apex and a high probability of seeds formation with changed morphotype in the lowest parts of the pod. It should be noted that for all zones of oil radish inflorescence, which were determined during the evaluation of fruit elements by morphotype (Fig. 3), similar peculiarities in seed formation were noted. Such features are clearly shown in Figs. 4–5.

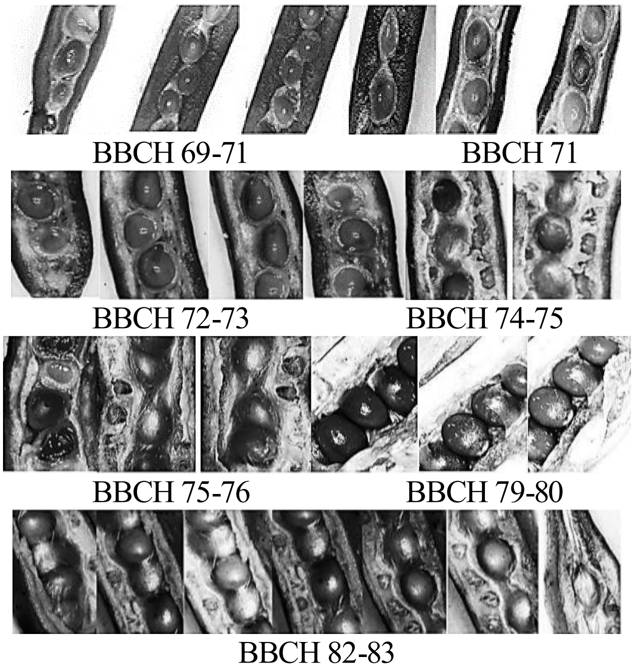


Figure 4. Nature of variability of oilseed radish seed size of the 'Zhuravka' variety in a pod at various microstages of its formation (in each line position of the figure from left to right: from the base of the pod to its apex), 2017.

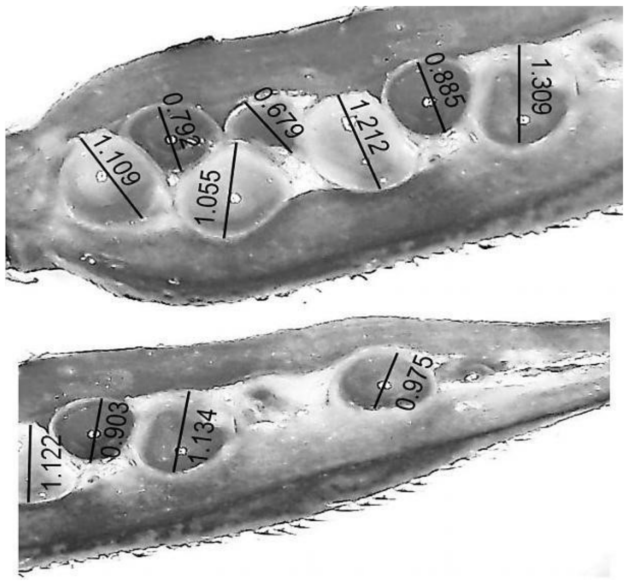


Figure 5. Nature of variability of oilseed radish seed size of the'Zhuravka' variety in a pod at various microstages of its formation position – seed size difference in the formation phase (BBCH 69-71, the dimension of values of mm), 2017.

As a result, for the period of waxy ripeness of seeds (brown pod phase BBCH 85-87) in the dynamic row of assessment of linear sizes of seeds, placed similarly to the pod from its base to the top, there is a gradual reduction of seeds in sizes and the appearance of atypical seeds in shape in the row of seeds by pod height. At the same time, the total number of seeds in the pod has an overall stable tendency to decrease. It was 1–3 seeds on average in comparison with the lower zone pods to the upper zone pods. This is clearly illustrated in Fig. 6. It should be noted that in contrast to rapeseed and mustard, for which the general nature of the variation of linear seed size is most significant in the upper and lower pod zones (Clarke, 1979; Smith & Scarisbrick, 1990; Bouttier & Morgan, 1992; Angadi et al., 2000; Garcia et al., 2005; Gunasekera et al., 2006; Vovchenko & Fursova, 2012; Zheng et al., 2017; Luo et al., 2018; Li et al., 2019), for oilseed radish such variability is more pronounced zonally and includes some seeds of the middle zone of the pod.

The data array obtained in the automated scanned images processing mode (Table 3) has confirmed the general conclusion about the presence of significant levels of matrix quality variability of seeds. In comparison with seeds from pods with different placement on the mother plant, respectively, for the lower and upper zones against the background of increased variation (according to the values CV (Zaytsev, 1984) projection surface area ofseeds (SA), medium and elevated levels of seed surface perimeter variation (P), medium variation level in length (L), width (W) and seed roundness (R) and, respectively, elevated variation level in seed sorting index (SI) – variation coefficient value was 0.7–3.6% higher for seeds from the upper zone pods.

It was also determined that the studied technological parameters influenced the value of variation of the specified morphological features of seeds. Thus, for all the stand densities under study, mineral fertilizer application contributed to the growth of the overall overall value of all the features without exception, with increasing dynamics, in line with the increasing rate of fertilizer application. This nature of influence is more pronounced in the formation of seeds from the pods of the upper zone with an increase to the unfertilized variant in the context of the studied technological variants of sowing rates from 1.3 to 2.4% in comparison to seeds from the pods of the lower zone in the range from 1.0 to 1.9%. The gradual increase in variation of morphological signs of seeds with a decrease in plant stand density and an increase in the area of their nutrition with a maximum expression at the application of fertilizers in the norm of 90 kg ha^{-1} of the primary material are determined. Thus, the difference in the average variation coefficient ($CV_{aver.}$, %) between the variant with the maximum stand density at the rate of 4.0 million of germinable seeds ha^{-1} with the fertilizer $N_{90}P_{90}K_{90}$ and the variant with the minimum stand density at the rate of 0.5 million of germinable seeds ha^{-1} was 7.2% for seeds from the pods of the lower zone and 10.1% for seeds from the pods of the upper zone.

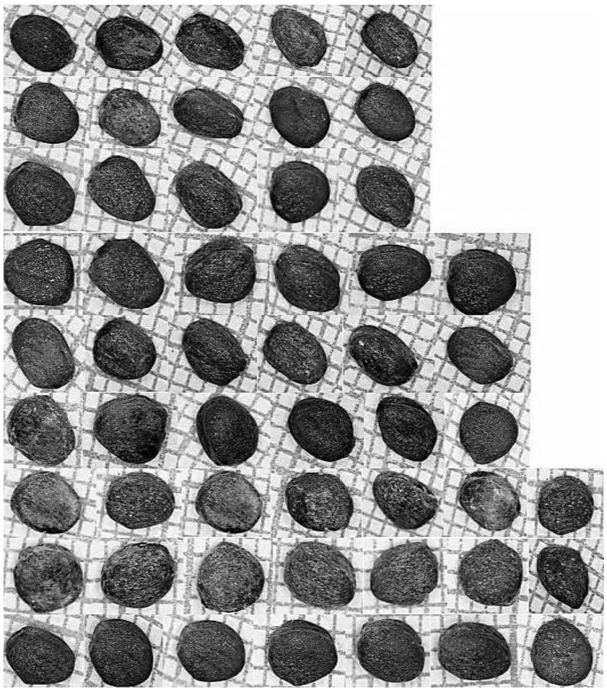


Figure 6. Qualityvariability of oilseed radish seeds of the‘Zhuravka’ variety in the order of their placement in the pods of various zones of the generative part (three upper positions - pods of the upper zone, three middle positions - pods of the middle zone, three lower positions - pods of the lower zone; placement of seeds on the rows of the figure from left to right in each row from the base of the pod to its apex), sampling selection of 2017.

As a result, according to the matrix variability index (MVI), the most significant gap in the morphology of seeds of pods of the lower and upper zones with the value of 0.86 was noted exactly for the variant of 0.5 million of germinables seeds ha^{-1} with the maximum fertilization with $N_{90}P_{90}K_{90}$. Similar features are noted in other cruciferous crops (Kitaeva, 1952; Tayo & Morgan, 1978; Morgan, 1980; McGregor, 1981; Voytenko, 1989; Lovett-Doust, 1989; Rao et al., 1992; Habekotté, 1996; Susko & Lovett-Doust, 2000; Faraji, 2010; Wang et al., 2011; Li et al., 2016, 2019, 2020).

Table 3. Variation coefficients (CV, %) of the main signs of oilseed radish seeds of the ‘Zhuravka’ variety according to the results of scanning of seeds for the brown pod phase (BBCH 85-86) in different stages of inflorescence at different variants of formation of agrophytocenosis on the average for 2013–2018, % (for *N* in the scanning group from 4,200 to 18,000)

Sowingrate and sowing method	Fertilizer	Morphological signs of seeds that were observed in the Digimizer image analysis software (v 4.2)														MVI
		PS, mm^2	P, mm	L, mm	W, mm	R, mm	SI	CV_{aver}, %	PS, mm	P, mm	L, mm	W, mm	R, mm	SI	CV_{aver}, %	
		Seeds from the pods of the upper generative zone							Seeds from the pods of the lower generative zone							
4.0 million, row	1	22.1	18.9	15.2	12.3	17.8	13.2	16.6	20.8	18.2	14.6	11.6	17.1	12.8	15.9	0.96
	2	22.7	19.1	15.8	12.6	18.2	13.9	17.1	21.2	18.4	15.1	11.8	17.3	13.2	16.2	0.95
	3	23.1	19.7	16.4	13.4	19.1	14.5	17.7	21.6	19.2	15.1	12.4	17.1	13.1	16.4	0.93
	4	25.2	20.4	17.2	14.3	20.6	15.4	18.9	22.2	19.5	15.3	12.6	17.4	13.5	16.8	0.89
3.0 million, row	1	23.5	20.4	16.2	13.7	18.4	14.9	17.9	22.6	19.1	15.1	12.3	17.9	13.4	16.7	0.94
	2	24.2	20.9	17.5	14.2	18.9	15.3	18.5	22.9	20.3	15.7	12.5	18.2	13.8	17.2	0.93
	3	25.1	21.4	18.2	14.9	19.5	15.8	19.2	23.2	20.6	15.9	12.8	18.3	13.9	17.5	0.91
	4	25.8	22.2	18.7	15.5	20.4	16.2	19.8	23.5	20.9	16.4	13.2	18.6	14.4	17.8	0.90
2.0 million, row	1	26.7	22.9	19.5	15.9	20.9	16.8	20.5	23.8	21.5	16.2	13.5	18.4	14.8	18.0	0.88
	2	27.4	23.4	19.8	16.7	21.3	17.2	21.0	24.2	21.8	16.7	14.2	18.8	15.1	18.5	0.88
	3	27.8	24.5	20.2	16.9	21.7	17.6	21.5	24.6	21.9	16.9	14.7	19.3	15.5	18.8	0.88
	4	28.3	25.2	20.7	17.3	22.4	17.9	22.0	24.9	22.3	17.2	14.9	19.7	15.8	19.1	0.87
1.0 million, row	1	27.9	23.5	20.8	16.7	21.7	18.2	21.5	25.2	23.7	17.2	15.1	20.6	16.7	19.8	0.92
	2	28.2	24.2	21.5	16.9	22.4	18.8	22.0	25.8	24.2	17.9	15.6	21.2	17.1	20.3	0.92
	3	28.9	24.7	22.3	17.2	22.8	19.1	22.5	26.2	24.7	18.5	16.3	21.7	17.4	20.8	0.92
	4	29.2	25.1	22.6	17.7	22.9	19.3	22.8	26.8	25.3	19.1	16.9	22.5	18.4	21.5	0.94
2.0 million, wide-row	1	23.5	19.2	15.7	12.9	18.4	13.8	17.3	21.5	18.6	14.9	12.2	17.5	13.1	16.3	0.94
	2	24.2	19.6	16.4	13.5	18.8	14.3	17.8	21.9	19.3	15.5	12.6	17.9	13.5	16.8	0.94
	3	24.8	20.1	16.8	14.2	19.2	14.9	18.3	22.2	19.5	15.8	12.7	18.3	13.9	17.1	0.93
	4	25.1	20.8	17.4	14.8	19.6	15.2	18.8	22.5	20.3	16.7	13.2	18.8	14.5	17.7	0.94
1.5 million, wide-row	1	25.2	21.8	17.8	14.9	19.1	15.6	19.1	23.4	19.5	15.5	13.4	18.2	13.7	17.3	0.91
	2	25.8	22.3	18.4	15.5	19.8	16.2	19.7	23.8	20.4	15.9	13.8	18.7	14.4	17.8	0.91
	3	26.1	22.9	19.2	15.8	20.6	16.9	20.3	24.2	20.6	16.3	14.2	19.1	14.8	18.2	0.90
	4	26.9	23.2	19.6	16.4	20.9	17.4	20.7	24.8	21.2	16.9	14.8	19.6	15.5	18.8	0.91
1.0 million, wide-row	1	28.1	23.5	20.6	16.4	21.7	17.5	21.3	26.1	24.5	17.8	14.8	19.5	15.2	19.7	0.92
	2	28.8	24.2	21.4	16.9	22.3	17.9	21.9	26.4	25.2	18.1	15.3	19.8	15.7	20.1	0.92
	3	29.5	24.8	22.5	17.4	22.9	18.5	22.6	26.8	25.7	18.4	15.5	20.1	15.9	20.4	0.90
	4	30.2	25.1	22.9	17.9	23.7	19.4	23.2	27.2	26.1	18.8	15.9	20.4	16.1	20.8	0.89
0.5 million, wide-row	1	30.7	29.2	22.8	18.7	24.5	21.3	24.5	28.2	27.3	19.3	16.4	21.5	16.9	21.6	0.88
	2	31.6	30.4	23.5	19.2	24.1	20.7	24.9	28.9	27.8	19.6	16.8	21.9	17.4	22.1	0.89
	3	32.3	31.4	24.1	19.8	24.7	21.1	25.6	29.2	28.1	20.4	17.2	22.4	17.9	22.5	0.88
	4	33.1	32.2	25.6	21.8	25.7	22.6	26.8	30.1	28.7	20.9	17.9	22.7	18.3	23.1	0.86
Tukey test upper/lower zone p_{adj}		0.00096**	0.04152*	0.06317*	0.03942**	0.04752*										

1 – Fertilizer-free; 2 – $N_{30}P_{30}K_{30}$; 3 – $N_{60}P_{60}K_{60}$; 4 – $N_{90}P_{90}K_{90}$. Tukey test: * – $P < 0.05$; * – $P < 0.001$.

In my opinion, the obtained values are determined by the peculiarities of relations between plants in populations of different densities. Thus, at maximum technological density, the level of variation of indicators is under much higher coenotic tension than in the variants of minimum technological density. Due to these regularities, the average value of a feature has a smaller scale of deviations, also in terms of morphometry of seeds and fruit elements. Mineral fertilizers should be considered in our system as stress regulators, which reduce the coenotic tension (Zlobin, 2009). For these reasons, the range of deviations from the average for the same density level of cenosis indicated by us also increases dynamically with a reduction of the coenotic tension at lower sowing rates. An important aspect in this context is to determine the role of hydrothermal conditions of oilseed radish vegetation on the general manifestation of the level of variation of morphological features of seeds, which was noted by a number of studies conducted on rapeseed (Rao et al., 1992; Morrison & Stewart, 2002; Gan et al., 2004; Lester et al., 2004; Luo et al., 2018). Comparison of factors of such influence (Fig. 7) allowed noting that decrease of hydrothermal coefficient (HTC) of oilseed radish vegetation period contributes to growth of general variability of seeds and expression of the effect of its matrix variability.

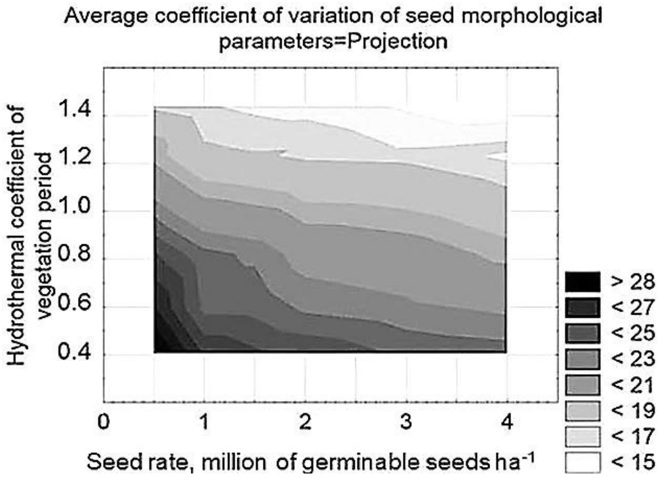


Figure 7. Dependence between the level of variation in the morphological parameters of oilseed radish seeds of the 'Zhuravka' variety, hydrothermal regime of the vegetation period and sowing rate of million germinable seeds ha^{-1} in conjunction with the width of the row spacing for the average for the fertilizer variants (consolidated data for the 2013–2018 period).

The maximum level of variation variability of morphological features of seeds at the level of CV = 27–30%, obtained at HTC in the range of 0.400–0.800 at sowing rate of 0.5–1.0 million germinable seeds ha^{-1}. Accordingly, the minimum level of variability of morphological features of seeds CV = 12–15% - when combined with the following parameters: HTC 1.3–1.4, 3.0–4.0 million germinable seeds ha^{-1}. Such results are quite consistent with our conclusions about the role of stress levels in the combination of density growth. An important component of the evidence of the above conclusions is the conducted fraction separation of oilseed radish seeds on the basis of the studied technological parameters of the construction of its agrophytocenosises. The results of seed separation on two types of sieves with round holes ((mm): 0.5; 1.0; 1.5; 2.0; 2.5; 3.0; 3.5; 4.0; 4.5; 5.0; 6.0; 7.0) (Table 4) and with rectangular holes (1.0×20; 1.2×20; 1.5×20; 1.7×20; 2.0×20; 2.2×20; 2.5×20; 3.0×20) (Table 5) allow us to generalize the peculiarities of the matrix variability of oilseed radish seeds.

Table 4. Fraction composition of oilseed radish seeds by its separation on sieves with round holes for the 'Zhuravka' variety on the brown pod phase (BBCH 85-87) in different tiers of inflorescence with different variants of agrophytocenosis formation on the average for 2013–2018,% (A factor - year)

Sowingrate (C), sowing method (B)	Fertilizer (D)**	Fractions by seed separationon sieves with rectangular holes, mm (%)															
		0.5	0.5	0.5	0.5	0.5	0.5	0.5	$m_{1,000}$, g	0.5	1.0	1.5	2.0	2.5	3.0	3.5	$m_{1,000}$, g
		Seeds from the pods of the upper generative zone								Seeds from the pods of the lower generative zone							
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*
4.0	1	7.2	20.6	26.3	25.8	20.1	0.0	0.0	7.6	3.8	14.2	17.3	30.8	33.9	0.0	0.0	8.3
million,	2	6.6	19.1	27.2	27.6	19.5	0.0	0.0	7.7	3.2	12.1	17.5	31.6	35.6	0.0	0.0	8.5
row	3	6.2	18.5	28.4	30.1	16.8	0.0	0.0	8.2	2.1	10.7	18.1	33.2	35.9	0.0	0.0	8.8
	4	5.4	17.7	29.2	31.3	16.4	0.0	0.0	8.4	1.8	8.5	18.7	34.4	36.6	0.0	0.0	8.9
3.0	1	6.4	19.4	28.4	26.7	19.1	0.0	0.0	8.0	2.6	13.4	18.2	31.6	34.2	0.0	0.0	8.6
million,	2	5.6	18.8	29.1	27.4	19.1	0.0	0.0	8.3	1.6	12.0	18.6	32.7	35.1	0.0	0.0	8,9
row	3	4.9	18.2	29.5	29.2	18.2	0.0	0.0	8.7	0.9	10.6	18.9	33.1	36.5	0.0	0.0	9.3
	4	4.6	17.4	30.2	30.7	17.1	0.0	0.0	9.0	0.6	9.2	19.2	33.8	37.2	0.0	0.0	9.5
2.0	1	5.3	16.8	29.3	27.9	20.7	0.0	0.0	9.2	1.1	13.8	19.2	31.4	34.5	0.0	0.0	9.7
million,	2	4.5	15.9	29.6	28.1	21.9	0.0	0.0	9.4	1.0	11.9	19.5	32.9	34.7	0.0	0.0	10.0
row	3	3.4	14.5	30.2	28.4	23.5	0.0	0.0	9.6	0.4	10.5	20.1	32.6	36.4	0.0	0.0	10.3
	4	2.7	13.8	30.8	29.2	23.5	0.0	0.0	9.8	0.4	8.3	20.7	32.4	38.2	0.0	0.0	10.6
1.0	1	3.7	15.9	30.6	28.2	21.6	0.0	0.0	9.7	0.0	11.7	20.4	32.4	35.5	0.0	0.0	10.0
million,	2	3.5	14.5	31.2	28.7	22.1	0.0	0.0	10.0	0.0	9.5	20.8	31.8	37.9	0.0	0.0	10.4
row	3	2.7	13.7	31.6	29.3	22.7	0.0	0.0	10.1	0.0	7.8	21.3	31.2	39.7	0.0	0.0	10.6
	4	1.9	12.9	32.2	29.7	23.3	0.0	0.0	10.4	0.0	5.7	21.5	31.6	41.2	0.0	0.0	10.8
2.0	1	6.1	18.4	26.9	27.3	21.3	0.0	0.0	8.2	2.1	13.1	18.5	33.4	32.9	0.0	0.0	8.7
million,	2	5.8	17.5	27.4	27.7	21.6	0.0	0.0	8.5	1.8	10.9	18.9	34.8	33.6	0.0	0.0	9.0
wide-row	3	4.8	16.8	28.5	28.2	21.7	0.0	0.0	8.8	0.8	9.2	19.4	36.5	34.1	0.0	0.0	9.2
	4	4.5	16.2	29.2	28.6	21.5	0.0	0.0	9.0	0.5	7.8	19.7	37.1	34.9	0.0	0.0	9.4
1.5	1	5.2	17.3	27.4	28.5	21.6	0.0	0.0	9.0	1.2	12.3	19.2	30.5	36.8	0.0	0.0	9.4
million,	2	4.8	16.7	28.1	29.1	21.3	0.0	0.0	9.2	0.8	11	19.6	30.4	38.2	0.0	0.0	9.6
wide-row	3	4.4	16.4	28.9	29.4	20.9	0.0	0.0	9.3	0.6	9.5	19.9	29.8	40.2	0.0	0.0	10.0
	4	3.9	15.9	29.5	29.8	20.9	0.0	0.0	9.7	0.4	6.8	20.6	29.5	42.7	0.0	0.0	10.2
1.0	1	4.5	15.2	29.2	23.3	27.8	0.0	0.0	9.5	0.0	11.5	20.9	25.7	41.9	0.0	0.0	10.2
million,	2	3.8	13.8	31.3	23.9	27.0	0.2	0.0	9.7	0.0	9.8	21.3	25.1	43.3	0.5	0.0	10.5
wide-row	3	3.5	12.6	32.6	24.2	26.8	0.3	0.0	9.9	0.0	7.2	21.6	24.3	46.1	0.8	0.0	11.0
	4	2.7	11.5	33.4	24.7	27.2	0.5	0.0	10.4	0.0	5.7	22.1	23.5	47.6	1.1	0.0	11.3
0.5	1	2.3	13.8	31.5	17.7	34.4	0.3	0.0	10.4	0.0	9.3	22.5	19.5	48.3	0.4	0.0	11.2
million,	2	1.9	12.7	32.7	17.9	34.3	0.5	0.0	10.8	0.0	7.8	22.8	19.3	49.3	0.8	0.0	11.5
wide-row	3	1.7	13.2	33.4	18.4	32.6	0.7	0.0	11.0	0.0	5.5	23.4	19.2	50.7	0.9	0.3	11.7
	4	1.5	11.3	34.3	18.6	33.4	0.9	0.0	11.1	0.0	3.8	23.8	19.4	51.6	1.1	0.3	12.0
$LSD_{05}A^{*}$		0.08	0.31	0.18	0.42	0.38			0.14		0.18	0.31	0.29	0.60			0.15
$LSD_{05}B$		0.05	0.18	0.10	0.24	0.22			0.08		0.10	0.18	0.16	0.35			0.09
$LSD_{05}C$		0.07	0.25	0.15	0.34	0.31			0.12		0.14	0.25	0.23	0.49			0.13
$LSD_{05}D$		0.07	0.25	0.15	0.34	0.31			0.12		0.14	0.25	0.23	0.49			0.13
$LSD_{05}AB$		0.12	0.43	0.25	0.59	0.53			0.20		0.25	0.44	0.40	0.86			0.22
$LSD_{05}AC$		0.17	0.61	0.36	0.84	0.75			0.29		0.35	0.62	0.57	1.21			0.31
$LSD_{05}AD$		0.17	0.61	0.36	0.84	0.75			0.29		0.35	0.62	0.57	1.21			0.31
$LSD_{05}BC$		0.10	0.35	0.21	0.48	0.43			0.17		0.20	0.36	0.33	0.70			0.18

Table 4 (continued)

1	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*
LSD_{05}BD	0.10	0.35	0.21	0.48	0.43			0.17		0.20	0.36	0.33	0.70			0.18
LSD_{05}CD	0.14	0.50	0.29	0.68	0.61			0.23		0.29	0.51	0.47	0.99			0.25
LSD_{05}ABC	0.24	0.86	0.51	1.19	1.06			0.41		0.50	0.88	0.81	1.71			0.44
LSD_{05}ABD	0.24	0.86	0.51	1.19	1.06			0.41		0.50	0.88	0.81	1.71			0.44
LSD_{05}ACD	0.34	1.22	0.72	1.68	1.50			0.57		0.71	1.25	1.14	2.42			0.62
LSD_{05}BCD	0.20	0.70	0.41	0.97	0.87			0.33		0.41	0.72	0.66	1.40			0.36
LSD_{05}ABCD	0.48	1.73	1.01	2.37	2.13			0.81		1.00	1.77	1.62	3.42			0.87
Share of influence A																
B	10.30	36.87	64.61	40.34	26.69			56.4		17.12	67.90	59.06	43.74			56.8
C	6.38	10.54	1.19	12.55	23.26			5.00		10.25	6.50	6.35	14.39			5.54
D	64.18	40.75	0.99	17.75	37.11			31.7		21.50	20.90	28.37	23.38			30.8
AB	15.15	9.88	1.89	2.55	0.20			4.99		47.41	3.40	3.61	5.48			5.24
AC	0.10	0.23	9.52	0.26	0.28			0.07		0.18	0.09	0.20	0.16			0.08
AD	0.91	0.65	7.87	0.26	0.59			0.56		0.30	0.43	0.52	0.41			0.54
BC	0.18	0.12	0.34	0.12	0.03			0.19		0.59	0.17	0.09	0.18			0.19
BD	0.88	0.13	1.28	23.64	8.18			0.48		1.09	0.32	0.53	11.29			0.46
CD	0.46	0.05	0.22	0.33	0.52			0.02		0.33	0.02	0.01	0.03			0.01
ABC	0.63	0.40	0.24	0.93	0.82			0.17		0.34	0.05	0.35	0.35			0.13
ABD	0.02	0.05	9.24	0.51	0.10			0.10		0.05	0.08	0.12	0.12			0.07
ACD	0.01	0.00	0.36	0.01	0.01			0.00		0.01	0.00	0.07	0.00			0.00
BCD	0.01	0.01	1.01	0.04	0.02			0.02		0.01	0.03	0.18	0.02			0.02
	0.76	0.31	0.12	0.67	2.15			0.13		0.78	0.08	0.33	0.41			0.04
	0.02	0.02	1.11	0.02	0.04			0.02		0.02	0.03	0.21	0.02			0.02

* – in the system of value expression at deprivation of values,%; ** – 1 – Fertilizer-free; 2 – $N_{30}P_{30}K_{30}$; 3 – $N_{60}P_{60}K_{60}$; 4 – $N_{90}P_{90}K_{90}$.

According to the data presented in both tables morphological row of oilseed radish seeds of the ‘Zhuravka’ variety is placed in the range of 0.5–3.5 mm for the sieves with round holes and 1×20–3×20 for the sieves with rectangular holes. This confirmed the affiliation of seeds to the general group a rounded and flattened. It also allowed recommending requires the introduction of a system of combined sieves for technological cleaning and calibration of oilseed radish seeds in production conditions. In addition, the array of data obtained indicates that the fraction composition of the size of seeds from pods of different zones of the plant is significantly different according to certain difference indices LSD_{05} for the main factors and their interaction. Thus, when separating seeds on round sieves (Table 4), given the significance of the difference between the studied variants, it should be noted a reliable increase in the percentage of fine fraction 0.5 mm in the seeds from the pods of the upper zone in the context of all the variants of standing density and fertilization. In fact, for variants 0.5–1.0 million germinable seeds ha^{-1} of this pod zone, this fraction was absent. As well as it is practically absent the fraction 3.0 and 3.5 mm for all technological variants. The distribution between the seed fractions in the range of 1.5–2.5 mm for seeds of the lower and upper tier of pods also differed significantly. Thus, on the average for the studied technological variants the seed fraction share of 2.0 mm and 2.5 mm for seeds from the pods of the lower zone was 29.83% and 39.40%, which is 11.8% and 69.0% higher than for seeds from the pods of the upper zone. At the same time, the actual nature of fractional distribution in all variants differed: the sum of fractions' share of 0.5–1.5 mm for seeds from pods of the lower zone averaged 30.57%, which is 19.33% lower than for seeds from pods of the upper zone. Seeds of 3.0 and 3.5 mm fractions in the research variants are stably noted for technological variants of 0.5 and 4.0 million germinable seeds ha^{-1} in the variant of $N_{60}P_{60}K_{60}$ and $N_{90}P_{90}K_{90}$ application. The role of mineral fertilizers in changing fractional composition of oilseed radish seeds also had its own peculiarities. Thus, for the variants of evaluation of fractional composition of seeds from the pods of the upper zone, the dynamic growth of fertilizer rates provided a decrease in the share of 0.5 and 1.0 mm seed fractions with adequate growth of other fractions. For seeds from the pods of the lower zone, the effect of mineral fertilizers was of two-level direction: a decrease in the share of the 0.5 mm fraction, 1.0 mm with the growth of other fractions. In case of wide-row sowing variants assuming the sowing rate of 1.5 million germinable seeds ha^{-1}, a decrease in the share of 2.0 mm seed fraction with an increase in the intensity of 2.5 mm share growth by 8.9–10.3% was noted. This indicates that on more dissolved sowings the character of formation of fractional composition of oilseed radish seeds has a more complex interfactional nature with the allocation of two or three main fractions. It should also be noted that the general regularity in the formation of fractional composition on the round sieves, despite the peculiarities in the fertilization section of specific technological variants, has its own characteristics for seeds from pods of both zones. Under these conditions, it is established that a stable growth of the share of large fractions of 2.0, 2.5 mm with a corresponding decrease of fractions of 0.5–1.0 mm. For certain technological variants, the impact of fertilizers on the proportion of the respective fractions had certain features, particularly for seeds from the pods of the upper zone for variants of 3.0–4.0 million germinable seeds ha^{-1} with normal row sowing and 1.5–2.0 million germinable seeds ha^{-1} with variants of wide-row sowing. It is proved that an increase in fertilizer rates ensured an increase in the share of seed fractions of 1.5 and 2.0 mm by 4.0–5.5 and 1.8–2.9%, respectively, while the share of seeds of 2.5 mm decreased by 2.0–3.7%.

The results of calculating the weight of 1,000 seeds are also important, as the matrix variability has weight expression and affects the level of individual seed productivity of plants (Makrushin, 1994). At a varietal idiotype of oilseed radish of the ‘Zhuravka’ variety with the index of mass of 1,000 seeds within 9–12 g, the studied technological approaches had essentially different efficiency of index formation including for seeds from pods of different zones. The average value of this indicator for the studied variants was 9.94 g for seeds from the pods of the lower zone and 9.33 g for seeds from the pods of the upper zone, which makes a difference of 6.5%. It should be noted that the difference in the value of the indicator differed within the technological options from 3.8% to 11.1%. Application of mineral fertilizers at a gradually increasing rate reduced the difference in weight of 1,000 seeds in comparison with seeds from pods of different zones by 1.3–3.7%. The maximum average difference in the value of the indicator for the two zones of pods was noted for the two extreme technological parameters in 4.0 and 0.5 million germinable seeds ha^{-1} - 8.8 and 8.2%, respectively. As a result, the weight of 1,000 seeds had a stable growth dynamics with an increase in the feeding area of one plant against the background of fertilizer increase to $N_{90}P_{90}K_{90}$ with a maximum value for both zones on the level of 11.1–12.0 g and a minimum value in the range of 7.6–8.3 for the non-fertilized background of 4.0 million germinable seeds ha^{-1}.

Table 5. Fraction composition of oilseed radish seeds by its separation on sieves with rectangular holes for the 'Zhuravka' variety on the brown pod phase (BBCH 85-87) in different tiers of inflorescence with different variants of agrophytocenosis formation on the average for 2013–2018, %

Sowingrate (C), sowing method (B)	Sowingrate (C), sowing method (B)	Fractions by seed separationon sieves with rectangular holes, mm (%)													
		1.0×20	1.2×20	1.7×20	2.0×20	2.2× 20	2.5×20	3.0×20	1.0×20	1.2× 20	1.7×20	2.0×20	2.2×20	2.5×20	3.0×20
		Seeds from the pods of the upper generative zone							Seeds from the pods of the lower generative zone						
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*8*	*10*	*11*	*12*	*13*	*14*	*15*	*16*
4.0	1	25.7	21.4	7.2	26.3	5.1	14.3	0.0	16.9	16.8	5.4	36.1	6.2	18.6	0.0
million,	2	25.0	21.9	7.6	25.2	5.5	14.8	0.0	16.3	17.4	5.7	35.2	6.7	18.7	0.0
row	3	21.5	22.9	7.9	24.7	7.4	15.6	0.0	14.8	17.8	5.9	34.7	7.2	19.6	0.0
	4	19.7	23.4	8.2	24.2	8.3	16.2	0.0	11.6	18.1	6.1	35.6	8.5	20.1	0.0
3.0	1	23.3	22.8	7.7	27.2	6.8	12.2	0.0	15.5	17.5	6.1	34.8	7.5	18.6	0.0
million,	2	22.6	23.1	8.1	26.8	7.2	12.2	0.0	14.7	18.2	6.7	33.7	7.9	18.8	0.0
row	3	21.3	23.8	8.5	26.2	7.8	12.4	0.0	12.5	18.7	7.1	32.1	9.3	20.3	0.0
	4	20.2	24.2	8.9	25.8	8.2	12.7	0.0	11.4	19.1	8.2	31.1	8.8	21.4	0.0
2.0	1	22.9	23.4	7.4	28.7	7.5	10.1	0.0	14.2	18.8	6.9	31.9	8.5	19.7	0.0
million,	2	21.5	23.9	8.1	27.4	7.9	11.2	0.0	12.3	19.1	7.3	32.2	8.9	20.2	0.0
row	3	20.1	24.6	8.5	26.5	8.3	12.0	0.0	10.2	19.8	8.2	31.5	9.4	20.9	0.0
	4	17.7	25.4	9.2	25.7	8.9	13.1	0.0	9.3	20.2	8.7	30.8	9.7	21.3	0.0
1.0	1	20.3	23.9	8.7	28.3	7.8	11.0	0.0	12.6	19.9	7.7	30.2	9.1	20.5	0.0
million,	2	19.2	24.2	9.2	27.8	8.1	11.5	0.0	11.4	20.4	8.8	28.6	9.4	21.2	0.2
row	3	18.5	24.8	9.6	27.4	8.5	11.2	0.0	10.8	20.6	9.1	27.1	10.3	21.8	0.3
	4	15.8	25.9	9.8	26.8	9.9	11.8	0.0	9.1	20.9	9.6	26.7	10.7	22.5	0.5
2.0	1	17.9	16.9	9.1	28.5	9.4	18.2	0.0	9.3	13.9	7.9	34.1	8.3	26.5	0.0
million,	2	16.8	17.2	9.5	27.8	9.8	18.9	0.0	8.3	14.1	8.2	33.5	9.1	26.8	0.0
wide-row	3	15.7	18.2	9.8	26.9	8.6	20.8	0.0	6.6	14.5	8.8	33.2	9.7	27.2	0.0
	4	14.2	18.8	10.1	26.2	9.5	21.2	0.0	4.9	14.7	9.1	33.5	10.2	27.6	0.0
1.5	1	16.3	16.6	10.4	27.4	7.8	21.5	0.0	8.9	12.6	8.4	32.6	8.9	28.4	0.2
million,	2	15.9	16.9	10.7	27.2	7.4	21.9	0.0	8.7	12.8	8.7	31.3	9.4	28.8	0.3
wide-row	3	14.7	17.5	11.3	26.8	5.9	23.8	0.0	6.4	13.9	8.9	30.9	6.9	32.7	0.3
	4	13.5	18.2	11.6	26.4	5.1	25.2	0.0	4.3	13.3	9.3	30.7	7.2	34.8	0.4
1.0	1	14.7	15.8	15.3	24.8	7.9	21.2	0.3	7.5	11.8	9.3	30.8	9.6	30.4	0.6
million,	2	13.2	15.3	15.9	23.9	8.5	22.7	0.5	7.2	12.4	9.6	28.6	10.5	30.9	0.8
wide-row	3	12.7	15.2	16.5	22.6	9.3	23.2	0.5	6.1	12.9	9.7	27.4	11.2	31.9	0.8
	4	11.9	14.6	16.9	22.4	9.8	23.7	0.7	4.7	13.3	9.9	27.3	11.8	32.2	0.8
0.5	1	13.8	14.8	16.3	20.9	11.2	22.5	0.5	7.4	9.3	9.8	29.6	12.3	30.9	0.7
million,	2	12.5	14.6	16.9	20.2	11.9	23.2	0.7	5.7	9.5	10.6	28.4	13.5	31.4	0.9
wide-row	3	11.6	14.2	17.5	19.4	12.6	24.0	0.7	5.3	10.3	10.8	24.1	14.8	33.8	0.9
	4	10.8	13.9	18.2	18.9	12.9	24.5	0.8	3.4	10.6	11.2	24.3	15.2	34.3	1.0
LSD_{05} A*		0.30	0.32	0.19	0.40	0.14	0.29		0.18	0.26	0.15	0.48	0.35	0.40	
LSD_{05}B		0.17	0.18	0.11	0.23	0.08	0.17		0.11	0.15	0.08	0.28	0.20	0.23	
LSD_{05}C		0.25	0.26	0.15	0.32	0.12	0.24		0.15	0.21	0.12	0.39	0.28	0.33	
LSD_{05}D		0.25	0.26	0.15	0.32	0.12	0.24		0.15	0.21	0.12	0.39	0.28	0.33	
LSD_{05}AB		0.43	0.45	0.27	0.56	0.20	0.42		0.26	0.37	0.21	0.68	0.49	0.57	
LSD_{05}AC		0.60	0.63	0.37	0.80	0.29	0.59		0.37	0.52	0.29	0.97	0.69	0.81	
LSD_{05}AD		0.60	0.63	0.37	0.80	0.29	0.59		0.37	0.52	0.29	0.97	0.69	0.81	

Table 5 (continued)

1	*3*	*4*	*5*	*6*	*7*	*8*	*8*	*10*	*11*	*12*	*13*	*14*	*15*	*16*
LSD_{05}BC	0.35	0.36	0.22	0.46	0.17	0.34		0.21	0.30	0.17	0.56	0.40	0.46	
LSD_{05}BD	0.35	0.36	0.22	0.46	0.17	0.34		0.21	0.30	0.17	0.56	0.40	0.46	
LSD_{05}CD	0.49	0.51	0.31	0.65	0.24	0.48		0.30	0.42	0.24	0.79	0.57	0.66	
LSD_{05}ABC	0.85	0.89	0.53	1.12	0.41	0.83		0.52	0.73	0.41	1.37	0.98	1.14	
LSD_{05}ABD	0.85	0.89	0.53	1.12	0.41	0.83		0.52	0.73	0.41	1.37	0.98	1.14	
LSD_{05}ACD	1.21	1.26	0.75	1.59	0.58	1.18		0.74	1.04	0.58	1.93	1.39	1.61	
LSD_{05}BCD	0.70	0.73	0.43	0.92	0.33	0.68		0.43	0.60	0.34	1.12	0.80	0.93	
LSD_{05}ABCD	1.71	1.78	1.06	2.25	0.82	1.66		1.04	1.47	0.83	2.73	1.96	2.28	
Share of influence														
A	20.4	22.3	12.3	55.01	22.8	13.8		8.74	21.41	30.21	57.43	20.33	23.03	
B	55.0	59.7	46.6	7.13	11.8	74.4		63.0	62.58	30.41	4.68	17.00	65.64	
C	12.7	3.51	24.1	8.39	32.4	0.31		8.26	0.60	27.53	30.28	35.53	4.68	
D	9.12	3.25	2.13	2.78	4.64	3.01		16.1	1.75	7.93	3.54	6.45	3.11	
AB	0.85	0.95	0.59	0.19	0.14	0.99		0.95	1.00	0.36	0.14	0.21	0.85	
AC	0.19	0.06	0.35	0.16	0.55	0.03		0.11	0.03	0.46	0.50	0.56	0.10	
AD	0.10	0.06	0.06	0.05	0.13	0.08		0.19	0.07	0.20	0.06	0.15	0.10	
BC	0.17	4.25	13.5	25.22	16.5	6.29		1.27	12.06	1.43	0.60	8.62	1.16	
BD	0.60	0.21	0.01	0.02	3.14	0.40		0.05	0.05	0.24	0.17	0.48	0.19	
CD	0.41	3.98	0.06	0.29	3.63	0.26		0.63	0.02	0.47	1.61	4.81	0.75	
ABC	0.02	0.13	0.16	0.61	0.24	0.07		0.01	0.28	0.10	0.09	0.12	0.04	
ABD	0.01	0.01	0.00	0.00	0.04	0.01		0.00	0.00	0.00	0.01	0.01	0.01	
ACD	0.01	0.07	0.01	0.02	0.08	0.01		0.01	0.01	0.02	0.05	0.10	0.01	
BCD	0.36	1.47	0.03	0.10	3.86	0.32		0.54	0.13	0.61	0.81	5.54	0.33	
ABCD	0.01	0.03	0.00	0.02	0.05	0.01		0.01	0.01	0.02	0.04	0.08	0.02	

* – in the system of value expression at deprivation of values,%; ** – 1 – Fertilizer-free; 2 – $N_{30}P_{30}K_{30}$; 3 – $N_{60}P_{60}K_{60}$; 4 – $N_{90}P_{90}K_{90}$.

Under these conditions have also determined that the share of influence of the studied factors had different efficiency in the formation of values of different fractions of seeds separated on the round sieves, and within certain zones of pods placement. The most determinant factors in the formation of indicators of fractional composition of seeds were determined as the conditions of the year (factor A) with the share of influence in the range 10.3–67.9, sowing rate (factor C) 0.99–64.18. For the share of row width (factor B) and fertilizer (factor D) 5.0–23.26 and 0.2–47.41, respectively.

The certain non-uniformity of influence of the studied factors and their interaction indicates the complex mechanism of formation of linear and weight characteristics of seeds within the limits of fruit elements at different levels of combination of factors of the research. However, the regulatory factors of fractional composition of seeds and the expression of its matrix quality variability can be placed in the following order of importance A>C>D>B>BC. Similar results were obtained with respect to the quality variability of seeds in fractional composition within different zones of oilseed radish fruit elements at its separation on the sieves with rectangular holes (Table 5). The presented nature of fraction distribution has a wider interval nature, which indicates in favor of technologically restricted variant of oilseed radish seed separation on round sieves. This is indicated particularly by the corresponding share of seed fractions with the size of 1.7×20 mm and 2.2×20 mm. The nature of the fractional composition was different for seeds from pods of different zones.

For the average variant on technological variants in seeds from pods of the lower zone of the generative part the share of fraction 1.0×20 mm is 45.1% lower than for the variant from pods of the upper zone. For fractions 1.2×20 and 1.7×20, respectively, it was 21.2% and 23.6% lower. However, the total increase in the share of fractions in the range from 2.0–2.5×20, was noted, respectively, by 21.7%, 13.3% and 45.5%. In addition, considering certain technological variants, the formation of fractional composition has the same features as in the case of separation on round sieves.These features include a consistent increase in the share of large seed fractions (2.2 and 2.5 mm) with an increase in a single plant's feeding area and an increase in background fertilizer. In addition, the nature of growth has two levels: one is observed in the range of normal line sowing. The other is observed in the range of wide-row sowing. Due to these reasons, the factor interaction of the research data system has a different nature of relationships among their values: B>A>C>D>BC. That is, the main components that determine the fractional distribution of seeds by separation on rectangular sieves is the width of row spacing and conditions of the year. It should also be noted that the sowing rate factor has two realizable components both as a single component and as its interaction with the width of row spacing.

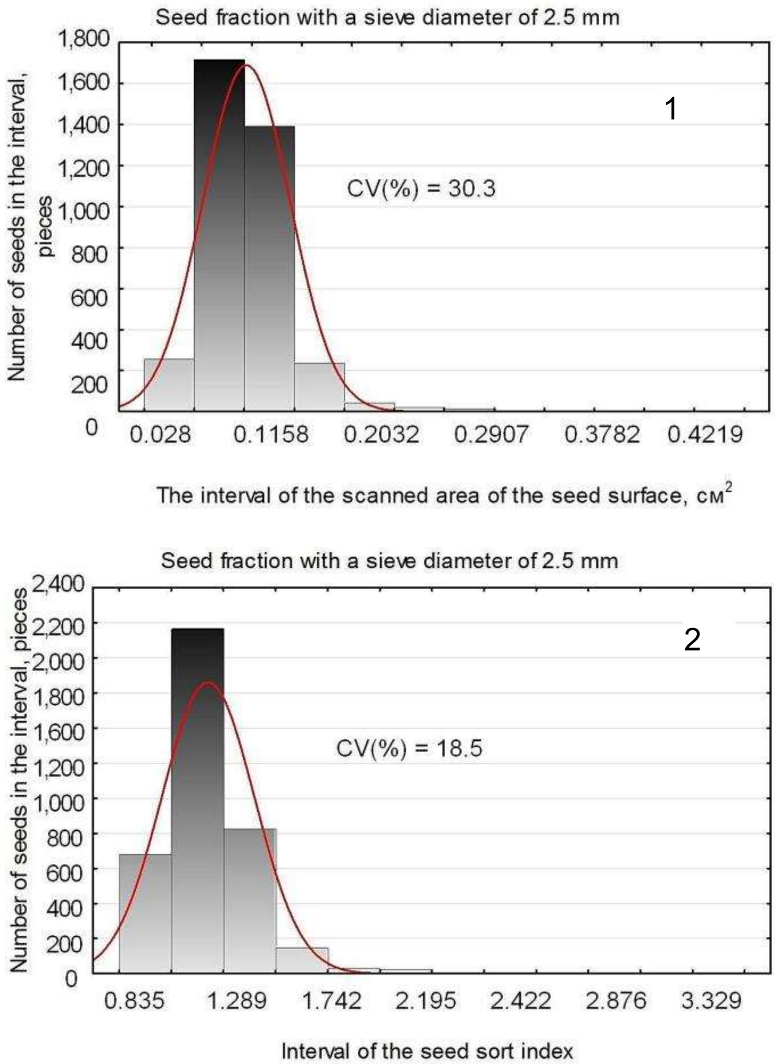


Figure 8. (a) Interval distribution of seeds of the 'Zhuravka' variety by indicators of the area of the scanned surface and sorting index of seeds for different fractions of seeds from the pods of the upper zone (position 1–2) of the generative part of plants with a technological variant of 2.0 million germinable seeds ha^{-1} with fertilizer N90P90K90, 2013.

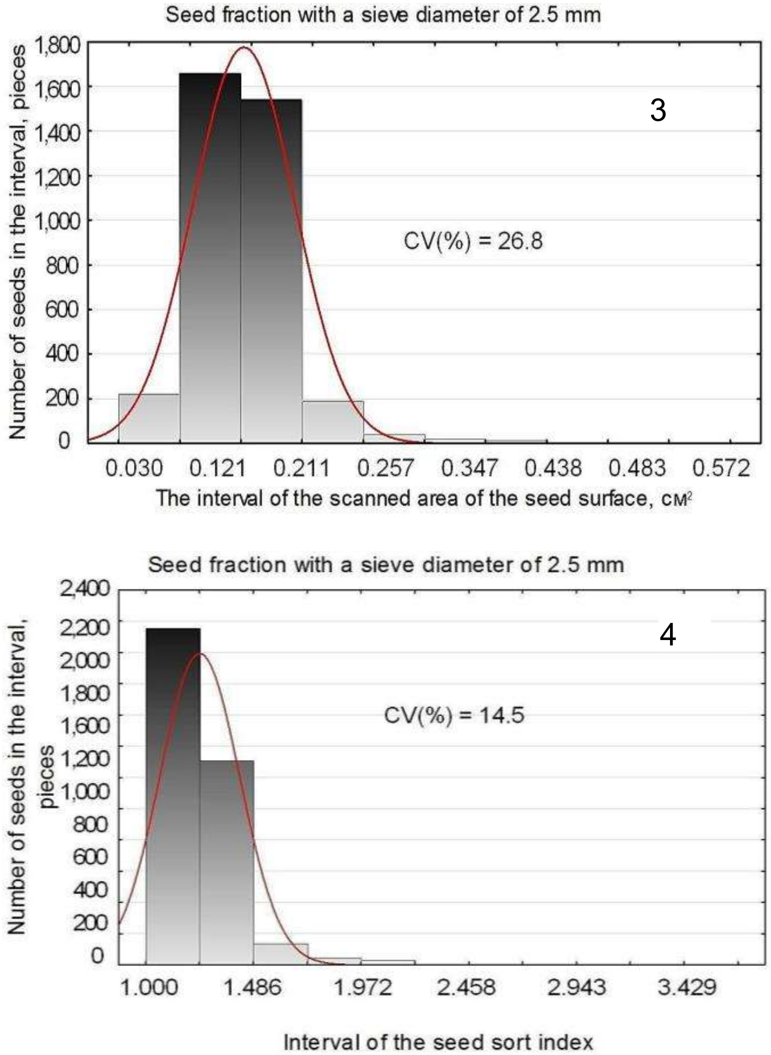
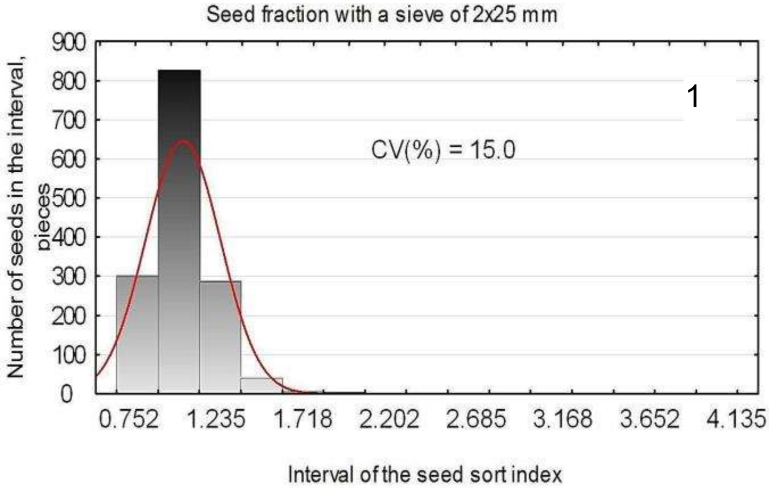


Figure 8. (b). The same from the pods of the lower zone (position 3–4), 2013.

On the other hand, it is important for practical seed production of cruciferous crops to understand the internal alignment of the received fractions of seeds (Würschum et al., 2012; Yang et al., 2016, 2017; Zheng et al., 2017). By applying the same electronic scanning approach to the separated seeds, we obtained its interval values of the morphological features of the seeds used to assess their variability (Table 3). So, for example, for the technological variant of 2.0 million germinable seeds ha^{-1} with fertilizer N90P90K90 (conditions of 2016), the nature of the interval row of seeds by the size of the area of the scanned surface (SA) andsorting index (SI) for two fractions of 2.5 mm (round sieves) (Fig. 8 (a, b)) and 2.5×20 (rectangular sieves) (Fig. 9) for different zone was different I also have found that the general variability of certain intervals for both given indicators on the value of the variation coefficient (CV) both for the fractions sieves is higher in the variant of seeds from the pods of the upper zone.

In particular, Figs 8, 9 gives an example of conditions for 2013 as approximate to the long-time average annual hydrothermal regime of vegetation of oilseed radish plants. Moreover, it should be noted that the difference in the variation coefficient between seeds from both pod zones was 3.5–9.7% higher for seeds from the upper zone. It was determined a higher value in the range of annual values for these deviations in the stress dry years (2015, 2017), and a lower value in the same range of values for conditions of years with moderate or optimal moistening (2013, 2014).



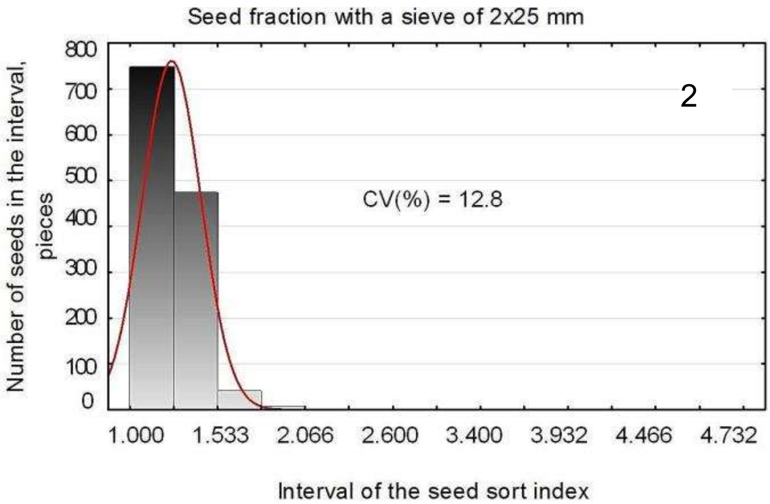


Figure 9. Interval distribution of seeds of the 'Zhuravka' variety by indicators of sorting index of seeds for seed fractions 2×25 mm from the pods of the upper zone (position 1) and from the pods of the lower zone (position 2) of the generative part of plants with a technological variant of 2.0 million germinable seeds ha^{-1} with fertilizer $N_{90}P_{90}K_{90}$, 2013.

It is also important that the general alignment of seeds from both zones of the generative part of plants is higher than the separation of seeds on rectangular sieves. For example, in Figs. 8 (a b) and 9, the coefficient of variation in the separation of seeds on round sieves was 2.2–5.4% higher, compared to a similar indicator for the separation of seeds on rectangular sieves.

CONCLUSION

Thus, on the basis of a comprehensive analysis of long-term data we have determined the presence of matrix quality variability of oilseed radish seeds both in morphological and weight characteristics according to the nature of placement of pods in the generative part of plants. The level of seed quality by matrix type in oilseed radish is determined by the nature of inflorescence formation and the corresponding morphotype of fruit elements, variable according to their height. The difference in the coefficient of variation of linear seed sizes was on average 6.7% higher for the upper zone of oilseed radish inflorescence compared to the lower zone. The maximum matrix variability of oilseed radish seeds was observed in the variant with a sowing rate of 0.5 million germinable seeds ha^{-1} against the background of the application of 90 kg ha^{-1} of mineral fertilizers. The integrated indicator of seed variability for this variant was the coefficient of 1.45 and 1.61 in comparison for the lower and upper inflorescence zones, respectively, in the system of the ratio of the two variants 0.5 and 4.0 million germinable seeds ha^{-1}. Mineral fertilizers contributed to the growth of seed variability in the range of 4.5–10.0% for the upper inflorescence zone depending on the cenosis design variant and 5.6–14.0% for the lower inflorescence zone. The heterogeneity of oilseed radish seed fractions in both round and elongated sieves was maximal at the minimum seeding rate on the background of maximum fertilizer. The summary result of the researchwas defined a decrease in the total linear individual size of oilseed radish seeds within the pod from the lower to the upper zone with a consistent reduction in the range of 3.8–8.3%, within the inflorescence in the range of 6.8–15.8%. An increase in the variation of seed morphoparameters in the comparison of the lower and upper zones of the inflorescence and pod by 7.2–10.2% with the maximum values of the growth of differences in the variants of the lowest seeding rate against the background of the maximum fertilizer $N_{90}P_{90}K_{90}$ was established.

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