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SEED PRODUCTION FROM DIFFERENT DEVELOPMENTAL STAGES OF CABBAGE POST VERNALISATION

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Abstract: Cabbage is a biennial vegetable species and, as such, it requires vernalisation to transition from the vegetative to the generative phase. This study compared and analysed the quality and seed production after overwintering and vernalisation of cabbage in the open field at several developmental phenophases. The first treatment was carried out at the technologically mature head (TMH) formation phenophase of cabbage. The second treatment included cabbage plants at the fully-developed leaf rosette (LR) phenophase, while the third treatment included cabbage plants after the development of all rosette leaves and the removal of head leaves (OIS). In the first and third treatments, the plants overwintered in the ground, whereas in the second treatment, the plants were allowed to grow and develop naturally in the open field. Average total seed weight per plant (the main component in the seed production) varied between 26.0 g under the outer and inner stem treatment and 81.3 g under the fully developed leaf rosette treatment. As anticipated, this trait differed significantly across all three treatments. The fully developed leaf rosette treatment produced a markedly higher seed weight per plant compared with both the technologically mature head and outer and inner stem treatments.

Key words: cabbage, temperature, vernalisation, seed.

Introduction

To obtain the appropriate marketable quality of cabbage heads, seed production plays an important role in the production itself. Cabbage seed production aims to create high-quality, healthy, certified and varietally pure seeds. The production is carried out under the professional supervision of agronomists to ensure optimal conditions for the development of the cabbage seed crop.

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In continental climates, cabbage seed production is mostly carried out in two ways. The first method involves burying/covering technologically mature heads with their root systems in a vertical position in the soil in the open field. The second method is overwintering in the open field, with vernalisation of the plant at the 7–10-leaf rosette stage (Červenski and Medić-Pap, 2018).

The goal of seed production is to obtain high-quality seeds. Cabbage seeds should have the highest germination energy and germination rate, the appropriate absolute weight, and the highest possible seed mass per plant. Seed quality plays a pivotal role not only in achieving the desired commercial quality of cabbage heads, but also in the production of any plant species (Poštić et al., 2022). However, the seed must also meet the minimum germination rate requirement of 75%, as prescribed by the Law on Seed (Demir et al., 2008; Official Gazette of SFRY and FRY, 2013).

The entire process of cabbage seed production in the open field is greatly influenced by climatic factors, both in the vegetative and the generative phases of production. During the winter-spring period, low temperatures are possible, ranging from 0°C to below -10°C, with mild or severe frosts. The vegetative cabbage head can undergo vernalisation at 4–5°C, while the most intensive processes occur at the temperature of 5–6°C. The vernalisation period ranges from 30 to 60 days. Vernalisation lasts about 7 weeks with 12 hours of daylight and a temperature of 6°C (Červenski et al., 2025).

Cabbage seeds are mainly produced using one of the two methods mentioned above, but due to climate change, seed production may undergo certain modifications. The first modification is overwintering, with vernalisation of cabbage during the phenophase of a fully developed leaf rosette when the head is formed and folded. The second modification requires removing all leaves of the rosette and those of the developed head, leaving intact only the inner stem of the cabbage head with the base of each true leaf, the central bud and the entire root system.

The aim of the paper was to examine the seed quality, analyse the mutual relationships, and compare the possibilities of cabbage seed production after overwintering and vernalisation using three different methods of seed production in the open field.

Materials and Methods

Experimental site

The field trial was set up in 2024–2025 at Rimski Šančevi, on a chernozem soil type, under an irrigation system at the Department of Vegetable and

Alternative Crops, Institute of Field and Vegetable Crops, Novi Sad (45°19'55.7"N, 19°50'14.9"E, and 86 masl).

The study included the late white cabbage variety Futoški, originating from Serbia and adapted to the continental European climate. Due to its high sugar content and thin leaves, the Futoški variety is commonly used for fresh consumption and pickling.

Sowing for the production of TMH seedlings started on 12 June, by dense sowing in rows. On 19 June, young plants were placed into boxes with space for 66 plants. Seedlings were grown in boxes until the stage of 6–7 true rosette leaves, which is the ideal time for transplanting. Transplanting into the open field, with interrow spacing of 70 cm and 50 cm, was conducted on 16 July 2024.

Sowing of the seeds for the production of LR seedlings started by dense sowing in rows on 7 August. On 19 August, young plants were placed into boxes, each accommodating 66 plants. The production of seedlings in boxes continued until the stage of 6–7 true rosette leaves, which is the ideal time for transplanting. Transplanting into the open field, with interrow spacing of 70 cm and 50 cm, was carried out on 10 September 2024.

The trial aimed to compare the possibilities of producing cabbage seeds using three different cultivation methods in open-field conditions, following vernalisation and overwintering. The trial included three different treatments (Figure 1).

Figure 1. Three tested treatments: TMH=first treatment, LR=second treatment, OIS=third treatment.
Source: Authors' own photograph.

The first treatment (technologically mature head – TMH) involved burying cabbage plants at the phenophase of technologically formed/rolled heads, without rosette leaves.

The second treatment (fully developed leaf rosette – LR) was modified in terms of plant development. We used plants with technologically unformed (loose) or unrolled heads (head growth and rolling phase) and a complete leaf rosette, in the natural climatic conditions of an open field, without burying and without protection from low temperatures.

The third treatment (outer and inner stem – OIS) involved selecting plants from the first treatment, from which we manually removed all rosette leaves and most of the head leaves with a knife, leaving only the inner core of the cabbage head with the base of each true leaf (2–3 cm), with dormant buds (lateral buds), and the central bud. The plants prepared in this way were then buried into the ground.

The plants from the first and third treatments were buried in a vertical position, with the upper part of the plant at the soil surface or 5 cm below. After placing the cabbage plants from the first and third treatments in the dug hole, we covered them with the excavated soil and, where necessary, made a mound/elevation of the soil above the buried plant, up to a maximum of 5–10 cm above the soil surface.

The interrow spacing was 60 cm in all three treatments. The intrarow spacing was 50 cm in all three methods.

Each treatment included 60 cabbage plants, totalling 180 plants. Plant height (in cm), defined as the height of the flowering stem from the soil surface to the highest flower on the plant, was measured during the intensive flowering phase. During the physiological maturity of the seeds, each plant was individually cut with scissors and placed in a paper bag for seed collection. The seed husks were hand-picked from each plant at physiological maturity. Seed extraction and threshing were performed manually, using scissors as needed. After extracting the seeds, the number of seeds per plant and the seed weight per plant (in grams) were measured, after which the seeds were placed in labelled paper bags. The labelled paper bags were stored in the Department's seed storage cold chamber at a constant air temperature of 5°C.

After completing all the samples, we removed the seeds from the chamber and analysed their physical and physiological properties: 1000-seed weight (g), germination energy (%) and total germination rate (%). The first count (germination energy) was recorded after 5 days, and the final count (total germination rate) was recorded after 10 days. The seed germination was determined following the guidelines of the International Rules for Seed Testing (ISTA Rules, 2017).

Climatic conditions

The seedlings were buried on 2 December 2024 in dry weather conditions in the first and third treatments. The winter season in continental Europe starts on 21 December and lasts until 20 March. Cabbage vernalisation occurred in the winter season in all three treatments. The mounds/elevations of the soil above the buried plants were loosened on 25 February 2025. The winter dormancy/overwintering period (from burying to loosening) lasted 85 days in all three treatments.

Table 1. Average temperatures over a ten-day period during the vegetative and generative phases of cabbage.

Ten-day month periods	Years/Months											
	2024						2025					
	Vegetative phase					Vernalisation			Flowering/seed production			
	VII	VIII	IX	X	XI	XII	I	II	III	IV	V	VI
01–10	25	24.8	25.4	15.4	8	4.3	5.3	2.7	9	8.7	16.6	23.6
11–20	30	29.7	16	13.8	3.5	4.2	-1.4	0.6	9.4	15.7	13.7	22.1
21–31	25.2	26.8	18.5	13.7	6.1	1.7	7.5	5.3	12.2	16.7	16.4	24.6
Average	26.7	27.1	20.0	14.3	5.9	3.4	3.8	2.9	10.2	13.7	15.6	23.4
Average 2014–2023	23.6	23.6	19.1	13.9	8.6	3.9	2.0	5.3	8.1	12.7	17.2	21.8

Source: Republic Hydrometeorological Service of Serbia, https://www.hidmet.gov.rs/.

During winter dormancy (vernalisation) from 2 December 2024 to 25 February 2025, the average air temperature in the open field ranged from -1.4 to 7.5°C. Because there were no serious frosts or low temperatures during this period, cabbage plants from all three treatments successfully vernalised and continued their generative development (Table 1).

Similar temperatures during the winter months were also recorded in the previous ten-year period, ranging from 2.0 to 5.3°C (Table 1).

In the study, the minimum soil temperature at a depth of 5 cm ranged from 1°C to 0°C in November and December 2024. From January to March 2025, the minimum soil temperature at a depth of 5 cm was 0°C, 0°C, and 2°C, respectively (Table 2).

Table 2. Minimum soil temperature (°C) at a depth of 5 cm.

Years	Months		Years	Months		
	XI	XII		I	II	III
2024	1	0	2025	0	0	2
Average 2014–2023	1.4	-0.4	Average 2014–2024	-1.4	-0.8	1.0

Source: Republic Hydrometeorological Service of Serbia, https://www.hidmet.gov.rs/.

Over the ten-year average, minimum soil temperature at a depth of 5 cm ranged from 1.4 to -0.4°C in November and December, and -1.4, -0.8 and 1.0°C in January, February and March (Table 2).

The timing for removing the soil mounds/elevation above the buried plants was determined by the onset of warmer weather in mid- to late February. During this period, the buried cabbage plants started to grow slowly, and the flowering stem emerged above the soil surface. Moreover, the plants in the second treatment, which had spent the winter in open-field conditions without burial or protection from low temperatures, also started to grow during this period.

Statistical analysis

Five replicates (plants) were analysed for each treatment. Statistical significance was assessed using the Bonferroni multiple test interval, with the significance level set at $p < 0.05$, to compare differences between treatments. A correlation study was conducted to assess the relationships between the evaluated traits. Pearson correlation coefficients were determined at the 0.05 and 0.01 probability levels. Data were processed in the software Statistica 13.2 (Dell Inc., USA).

Results and Discussion

Mean values for plant height (height of the fully developed flowering stem at flowering) ranged from 45.3 cm (OIS treatment) to 85.4 cm (LR treatment). Based on the height of the flowering stem, a significant difference was observed among the three treatments. Treatment LR produced a significantly taller flowering stem than the other two treatments (TMH and OIS). The lowest flowering stem height was recorded in treatment OIS (Figure 2-A).

Mean values for the number of seeds per plant ranged from 5016 seeds (OIS treatment) to 26203 seeds (LR treatment). The number of seeds per plant also showed significant differences among the three treatments. Treatment LR had the highest value for this trait compared to the other two treatments (TMH and OIS). The lowest number of seeds per plant was recorded in the OIS and TMH treatments (Figure 2-B).

Mean values for the total seed weight per plant ranged from 26.0 grams (OIS treatment) to 81.3 grams (LR treatment). As expected, seed weight per plant showed significant differences among the three treatments. The LR treatment recorded a significantly higher value for this trait compared to the other two treatments (TMH and OIS) (Figure 2-C).

Mean values for 1000-seed weight ranged from 3.3 grams (TMH and LR treatments) to 6.0 grams (OIS treatment). This trait showed slightly different results between the treatments compared to the previous traits. The OIS treatment had a significantly higher value for 1000-seed weight compared to the TMH and LR treatments, which had significantly lower values. However, no significant difference was observed between the TMH and OIS treatments, indicating that both treatments had similar values for this trait (Figure 2-D).

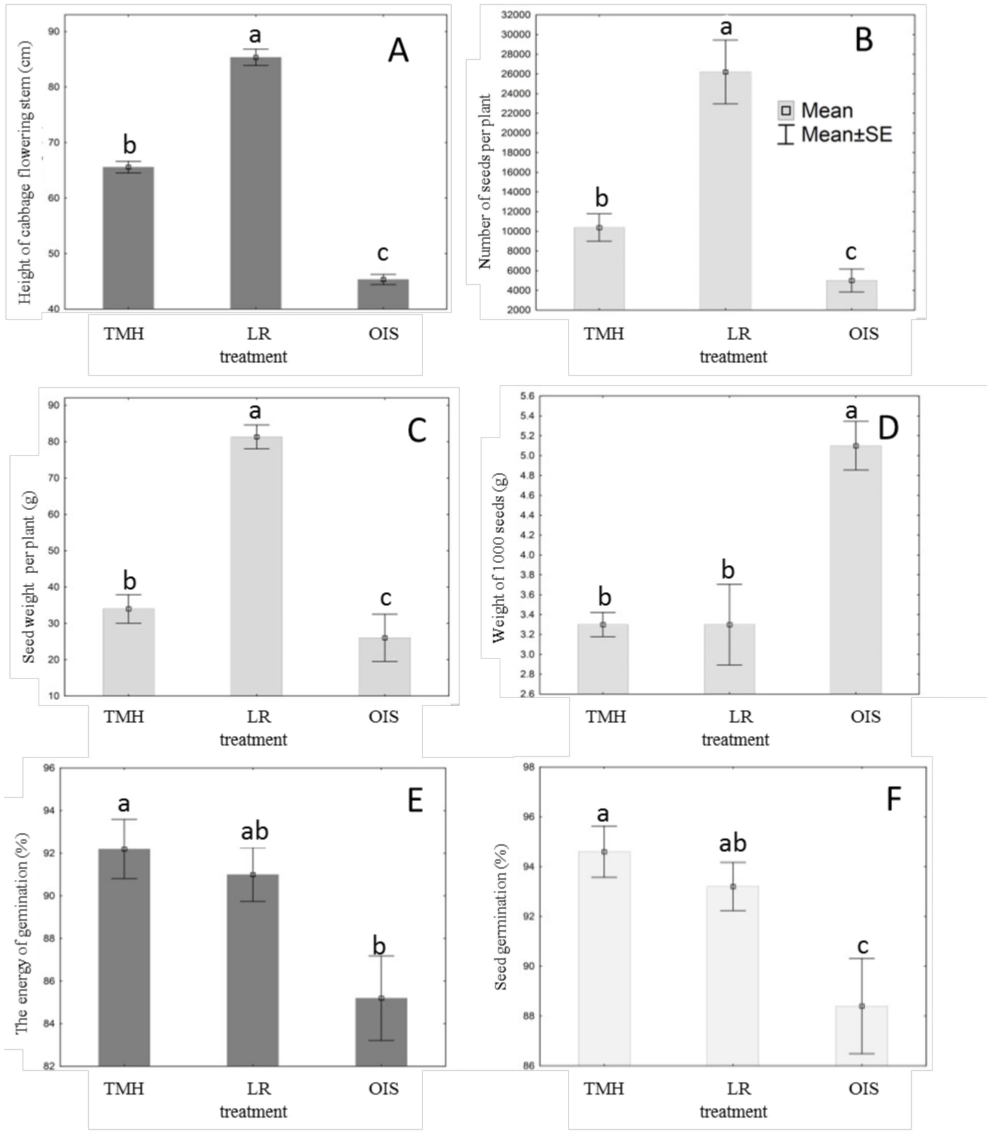

Figure 2. Mean values and standard errors for six investigated traits: A=height of cabbage flowering stalk (cm); B=number of seeds per plant; C=seed weight per plant (g); D=weight of 1000 seeds (g); E= germination energy (%); F=seed germination (%).

Source: Authors' own data and analysis.

Mean values for seed germination energy per plant ranged from 85.2% (OIS treatment) to 92.2% (TMH treatment). Seed germination energy was significantly highest in the TMH treatment, but only compared to the OIS treatment. The OIS treatment had the significantly lowest value for this trait compared to the TMH treatment (Figure 2-E).

Mean values for seed germination per plant ranged from 88.4% (OIS treatment) to 94.6% (TMH treatment). Treatment differences in seed germination were similar to those for germination energy. The highest seed germination was achieved in the TMH treatment, but only in comparison to the OIS treatment, which had a significantly lower seed germination value only in comparison to the TMH treatment (Figure 2-F).

The highest mean values for plant height, number of seeds per plant and seed weight per plant were achieved in the LR treatment. This means that the climatic conditions were quite suitable for the plants in this treatment.

Observing the mean values of the analysed traits across the treatments in Figure 2, it is evident that only the 1000-seed weight reached its highest value in the third treatment (OIS), while the mean values for the other studied traits were the lowest in this treatment compared to the other traits and treatments. This phenomenon is also illustrated in subfigures 2A, 2B, and 2C, where the third treatment (OIS) exhibited the lowest flowering stem height, the lowest number of seeds per flowering stem, and the lowest seed weight per plant. Since it had the lowest values among all treatments, the plants from the third treatment (OIS) produced fewer seeds per plant, which resulted in a higher absolute seed weight in this treatment (OIS) (Figure 2-D).

Plant height showed highly significant positive correlations with seed weight per plant (0.86) and number of seeds per plant (0.82). Significant positive correlations were also observed between plant height and germination energy (0.53) and seed germination (0.51). Plant height had a highly significant negative correlation with 1000-seed weight (-0.66).

Cabbage is a biennial plant species that forms heads in the first year and develops generative organs in the second year of production (Červenski et al., 2022).

Utilising the vernalisation phase for stable seed production is possible in continental climate conditions; however, the seasonal factor can be limiting due to the occurrence of extremely low negative temperatures that can destroy the crop (Adžić et al., 2023).

Cabbage seeds can be produced in several ways, but in continental conditions, two methods are most common. The first method involves producing technologically mature cabbage heads and burying/covering the heads underground in the first year, followed by vernalisation, flower formation, and seed production in the second year. The second method is the open field production, where cabbage plants form 7–10 true leaves of the rosette.

Table 3. Correlations between the studied cabbage traits.

Variable	Seed weight per plant (g)	Number of seeds per plant	1000-seed weight (g)	Seed germination energy (%)	Seed germination (%)
Plant height (cm)	0.86 **	0.82 **	-0.66 **	0.53 *	0.51 *
Seed weight per plant (g)		0.89 **	-0.42	0.29	0.34
Number of seeds per plant			-0.69 **	0.43	0.41
1000-seed weight (g)				-0.67 **	-0.56 *
Seed germination energy (%)					0.94 **

Significance level: *=0.05; **=0.01.
Source: Authors' own calculations.

This research examined the possibility of overwintering, vernalisation and production of cabbage seeds from three different treatments under the open-field growing conditions. During vernalisation, all three treatments were influenced by the temperature conditions of the open field. The average daily temperatures during this period, i.e., from December to the end of February, ranged from -1.4 to 7.5°C.

The vernalisation process, which affects the timing of flowering, depends on the temperature conditions. The most intensive vernalisation occurs at temperatures of 5–6°C. Before cabbage becomes susceptible to low temperatures (4–10°C) for 4–12 weeks, it must reach a certain developmental stage (7 to 9 leaves or 5–6 mm in stem diameter) (Červenski and Medić-Pap, 2018; Murat Dogru et al., 2020; Wohlfeiler et al., 2022; Bute et al., 2023). The results of this study are in agreement with the cited studies, and plants from all three treatments successfully overwintered, underwent vernalisation and formed a flowering stem with seeds.

However, the production of cabbage seeds under abiotic stress conditions, such as winter freezing with prolonged frost, can affect plant structure and the quality of traits that constitute the components of yield (Adžić et al., 2025).

Vernalisation is a physiological process that occurs due to the influence of low temperatures on cabbage plants. Further changes in environmental temperatures enable stem development, flowering and seed formation. During the winter-spring period, low temperatures can range from 0 to -10°C with varying degrees of frost. Such conditions can damage or even destroy individual plants in the open field (Červenski et al., 2022).

Cabbage plants are sensitive to subzero temperatures during the head formation phenophase, which limits seed production from cabbage heads. The Mediterranean region of Europe is well suited for cabbage seed production due to the short periods of subzero temperatures, during which cabbage heads do not require any covering (Adžić et al., 2023).

The height of the flowering stem ranged from 42.9 to 89.9 cm in this study, and from 135.68 to 188.04 cm in the research by Sharma et al. (2025). The differences between our results and those cited are due to the use of different varieties in the trials, variable climatic conditions, and applied agricultural techniques.

The number of seeds per plant varied from 2140 to 36800 in our study, and from 2050.28 to 5369.88 in the research by Sharma et al. (2025). The number of seeds per plant is a varietal characteristic and is influenced by both climatic and agrotechnical conditionsTaller flowering plants usually form more shells with a greater number of seeds per plant, which was probably the reason for this variability. The number of seeds per plant had a highly significant negative correlation with 1000-seed weight (-0.69). This correlation means that if a plant produces a large number of seeds, the mass of 1000 seeds will be lower, and vice versa.

The mass of seeds per cabbage plant in this study ranged from 10.7 to 92.1 grams. The obtained values are consistent with the findings of other authors, where the seed weight per plant ranged from 5.3 to 113.42 g/plant (Bhat et al., 2017; Murat Dogru et al., 2020; Adžić et al., 2025; Sharma et al., 2025). The similarity in seed mass per plant is likely due to the comparable habitus of the plants at the time of grain filling and harvest. Seed weight per plant (g) showed a highly significant positive correlation (0.89) with the number of seeds per plant. This correlation confirms the fact that a higher number of seeds per plant directly increases the seed mass per plant.

The 1000-seed weight of the three tested treatments ranged from 2.0 grams to 6.0 grams. The results are in agreement with those obtained by other studies, where 1000-seed weight ranged from 2.77 to 6.17 g (Demir et al., 2008; Adžić et al., 2012; Bhat et al., 2017; Bute et al., 2023; Sharma et al., 2025). It should be emphasised that a larger 1000-seed mass also means a larger seed volume, but seeds of different sizes can be found within the same shell. The 1000-seed weight had a highly significant negative correlation (-0.67) with germination energy, and a significantly negative correlation (-0.56) with seed germination. This means that a greater 1000-seed mass may be associated with lower germination energy and a reduced germination rate.

The seed germination energy obtained from all three treatments ranged from 82% to 95% in this study, and from 75.5 to 96% in similar studies conducted by other researchers (Adžić et al., 2012; Poštić et al., 2022). Seed germination ranged from 82% to 97% and was within the range of 85.5% to 99% reported by similar studies (Demir et al., 2008; Adžić et al., 2012; Bhat et al., 2017; Poštić et al., 2022; Bute et al., 2023). Seed germination energy showed a highly significant positive correlation (0.94) with seed germination (Table 3). Higher germination energy in cabbage contributes to more uniform seed germination and initial growth of cabbage seedlings.

Significant positive correlations with seed germination were found for seed weight per plant (0.60) and germination energy (0.57). A highly significant positive correlation was also found between germination energy and seed germination (0.97) (Adžić et al., 2021).

A highly significant positive correlation was found between germination energy and seed germination (0.847) (Poštić et al., 2022).

The aforementioned authors have further stated that the oldest plants always overwinter best, but also that plants with a small amount of vegetative biomass are unsuitable for overwintering (Adžić et al., 2023).

The “seed-to-seed” method is the most commonly used method in seed production for cabbage (Murat Dogru et al., 2020).

Temperatures below 0°C are not effective for vernalisation, so they were not included in the calculation of heat sums (Murat Dogru et al., 2020).

It should also be noted that cabbage plants contain over 92% water, and prolonged exposure to temperatures below 0°C can have a detrimental effect on the plant. For this reason, the climatic conditions of seed production environments must be well understood.

Conclusion

Comparing the mean values of seed quality across three different treatments, after overwintering and vernalisation, the TMH treatment (buried technologically mature heads) and the LR treatment (plants with fully-developed leaf rosettes, where heads were formed in the natural climatic conditions of an open field without burial), achieved better seed quality and seed production compared to the third treatment (OIS).

For this reason, the TMH and LR treatments can be recommended for cabbage seed production, resulting in good seed quality in continental open-field conditions.

The third treatment (OIS) can be used for seed production only in exceptional cases, if the TMH and LR treatments are not feasible.

Under the current climatic conditions, it is essential to become as familiar as possible with local production conditions to maximise theseed potential of each individual cabbage plant.

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PRODUKCIJA SEMENA NAKON PROLASKA JAROVIZACIJE RAZLIČITIH RAZVOJNIH FAZA KUPUSA

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R e z i m e

Kupus je dvogodišnja povrtarska vrsta u pogledu proizvodnje semena i potrebna mu je jarovizacija za prelazak iz vegetativne u generativnu fazu. U istraživanju su upoređeni i analizirani kvalitet i produkcija semena nakon prezimljavanja i prelaska jarovizacije različitih razvojnih fenofaza kupusa na otvorenom polju. Prvi tretman je uključivao fenofazu kupusa sa tehnološki zrelom glavicom (TZG), drugi tretman je uključivao fenofazu kupusa sa potpuno razvijenom lisnom rozetom ali sa nerazvijenom glavicom (LR), treći tretman je uključivao fenofazu kupusa sa odsečenim svim listovima rozete i listovima glavice (SUK). Prvi i treći tretman su prezimljavali sa jarovizacijom ukopani u zemlju, a drugi tretman je prezimljavao sa jarovizacijom bez ukopavanja u prirodnom rastu i razvoju na otvorenom polju. Prosečna ukupna masa semena po biljci (glavna komponenta u proizvodnji semena) varirala je između 26,0 g kod tretmana spoljašnjeg i unutrašnjeg stabla i 81,3 g kod tretmana potpuno razvijene lisne rozete. Kao što se i očekivalo, ova osobina se značajno razlikovala između sva tri tretmana. Tretman potpuno razvijene lisne rozete proizveo je znatno veću masu semena po biljci u poređenju sa tretmanima tehnološki zrele glave i spoljašnjeg i unutrašnjeg stabla.

Ključne reči: kupus, temperatura, jarovizacija, seme.

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