Scientific Papers. Series A. Agronomy, Vol. LXVIII, No. 2, 2025
ISSN 2285-5785; ISSN CD-ROM 2285-5793; ISSN Online 2285-5807; ISSN-L 2285-5785

INFLUENCE OF SOWING DENSITY ON GROWTH PROCESSES OF AMARANTHUS PLANTS IN THE CONDITIONS OF SOUTHERN UKRAINE

Nataliia VALENTIUK[1], Yevgen YURKEVYCH[2], Olesia DROBIT[1], Anatolii TOMNYTSKYI[1], Elgudzha KULIDZHANOV[1, 3]

[1]Institute of Climate Smart Agriculture of the National Academy of Agrarian Sciences of Ukraine, Mayatska Road Street, 24, Hlibodarske Village, Odesa, Ukraine
[2]Odesa State Agrarian University, Kanatnaya Street, 99, Odesa, Ukraine
[3]Southern Interregional Center of the SI Institute of Soil Protection of Ukraine, Laboratornaya Street, 19, Lymanka Village, Odesa, Ukraine

Corresponding author email: naval100@ukr.net

Abstract

Recently, the population of Ukraine has been paying more attention to a balanced diet and preferring products that contain the necessary complex of proteins, fats, carbohydrates, vitamins and micro- and macro elements. To meet such needs, manufacturers are constantly replenishing the range of products by adding non-traditional types of food raw materials to the recipes. One of these is a fairly new agricultural crop for our country - Amaranth. The extremely wide possibilities of using Amaranth are gradually increasing the demand for its production. This encourages agro-producers to improve cultivation technology, to obtain stable high yields of grain of this crop. One of the ways to increase the yield of agricultural crops is to regulate the sowing density. This measure allows plants to develop well and accumulate above-ground mass for the formation of a subsequent harvest. The article presents the results of a study of the Amaranth plants growth and development peculiarities depending on the post-emergence plant density. The highest values of amaranth plant height were recorded at the highest post-emergence plant density ($180 \cdot 10^3$ plants/ha). In the phase of full grain ripeness, amaranth plants of the Kharkivs`kyi 1 variety were 164.0 cm high, plants of the Liera variety were 170 cm high. The greatest stem thickness was at a post-emergence plant density of 90 $10^3$ plants/ha. The stem thickness of plants of the Kharkivs`kyi 1 variety was 3.0 cm, the stem thickness of plants of the Liera variety was 3.2 cm. The greatest values of (Leaf mass ratio) LMR were at a post-emergence plant density of 150 10^3 plants/ha. For the Kharkivs`kyi 1 variety, this indicator was 0.197 g/g, and for the Liera variety it was 0.232 g/g. To ensure the best conditions for plant growth and development, the optimal post-emergence plant density was 150 10^3 plants/ha. The obtained results will help agricultural producers to optimize the sowing parameters when growing Amaranth.

***Key words**: Amaranth, plant growth and development, phenological observations, post-emergence plant density, sowing parameters.*

INTRODUCTION

Human health depends on many factors, including nutrition. Recently, food manufacturers and farmers have been paying considerable attention to the development of new recipes of food products, enriching them with unconventional types of food raw materials. Amaranth is one of such types of non-traditional plant raw materials for Ukraine (Sots et al., 2024; Yaniuk et al., 2022).

Amaranth is a valuable fodder, grain, technical, food, medicinal and vegetable crop (Figure 1).

The green mass, the yield of which reaches 100 t/ha, is used in animal husbandry in fresh form, for making silage with other crops, and for obtaining protein-vitamin flour and compound feed. The protein of the green mass of amaranth has high nutritional value (Adhikary et al., 2020; Hoptsii et al., 2018; Joshi et al., 2018).

Of particular value is Amaranth oil, which contains up to 18% squalene and almost 76% unsaturated fatty acids (Levchuk et al., 2015; Malik et al., 2023).

Amaranthus is an annual, monoecious plant from the *Amaranthaceae* family (Hoptsii et al., 2018; Weerasekara et al., 2020; Joshi et al., 2018). Amaranth is a fairly tall, branched, well-leafed plant.

The stem of Amaranth is 1 to 3 meters high, straight and has an unevenly rounded, grooved shape, bright red or green color. Plants acquire branching in a sparse stand (Hoptsii et al., 2018; Joshi et al., 2018).

The leaves of the plant are arranged alternately, whole, elongated at the base into a petiole. They

are oval, rhombic, ovate, lanceolate in shape. The color varies from shades of purple, orange, red and green, depending on the species (Hoptsii et al., 2018; Weerasekara et al., 2020). The inflorescence is a complex panicle 23-57 cm long, which has a green, golden or red color of varying intensity. Amaranth flowers are typically bisexual and actinomorphic, small, consist of five petals with five stamens, collected in a panicle (Joshi et al., 2018; Weerasekara et al., 2020).
Amaranth root is taproot, thickened near the root neck, branched in the arable layer. At the same time, the taproot makes up about 50% of the total mass of the root system, 18-20% are first-order roots, 30-32% are second-order roots (Hoptsii et al., 2018; Weerasekara et al., 2020).
Amaranth seeds have a rounded lenticular shape, a smooth surface and are small in size (depending on the variety from 0.3 to 2.5 mm) (Hoptsii et al., 2018). The mass of 1000 seeds ranges from 0.6 to 1.2 g depending on the varietal characteristics and growing conditions (Hoptsii et al., 2018).

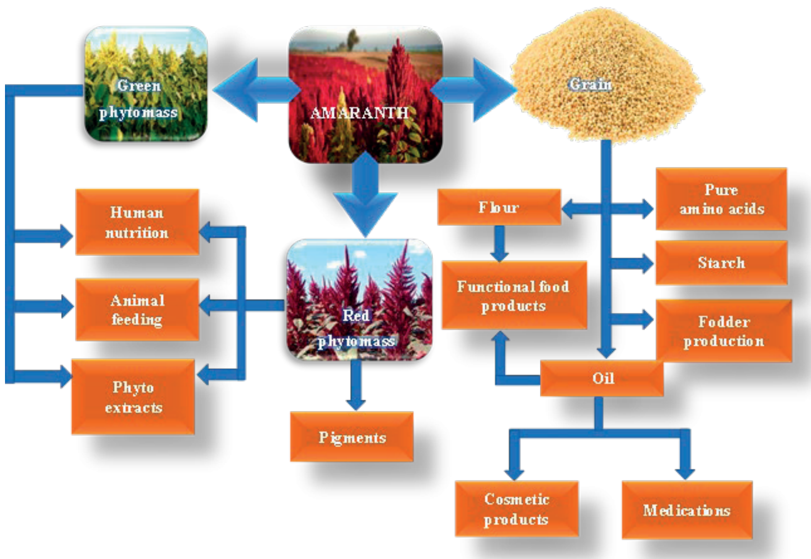

Figure 1. Modern use of amaranth phytomass and graine. Source: Authors' concept of the experiments

Amaranth is a thermophilic plant. The optimum temperature for photosynthesis is around 40°C, which is 10-15°C higher than most traditional crops (Hoptsii et al., 2018; Weerasekara et al., 2020; Joshi et al., 2018).
Amaranth is a plant of tropical origin with C_4 photosynthetic pathway (Hoptsii et al., 2018). This plant has a high ability to withstand environmental stress, which makes it a crop suitable for growing in extremely dry conditions caused by climate change (Weerasekara et al., 2020).
Amaranth grows on various types of soil in forest, forest-steppe and steppe zones, except for very acidic and saline soils, and soils with close groundwater (Mambetova et al., 2022; Dudka, 2019).
The uniqueness of this plant is evidenced by the fact that, unlike other crops, amaranth consumes the least amount of water to form 1 g of dry matter (Silva et al., 2019). According to research, it was found that amaranth consumes of 260 g water to form 1 g of dry matter while millet requires 300 g, corn requires 370 g, barley requires 520 g, wheat requires 550 g, sunflower requires 600 g, rye requires 630 g, clover requires 640 g, bean requires 700 g, alfalfa requires 840 g. (Silva et al., 2019). This makes amaranth promising for cultivation in a zone of insufficient and unstable moisture, which includes the Southern Steppe of Ukraine.
Despite the presence of a significant number of scientific studies related to the study of the biochemical composition of various parts of amaranth plants, directions and features of breeding work to develop new varieties, possibilities of use as food and medicinal raw

materials (Weerasekara et al., 2020; Idowu-Agida et al., 2020), substantiation of post-harvest processing and storage regimes of amaranth grain (Stankevych et al., 2021; Valentiuk et al., 2020), there are some contradictions regarding agrotechnical techniques aimed at increasing amaranth productivity (Dudka, 2019; Pelech et al., 2021; Tyrus et al., 2023). This is especially true for the optimization of the sowing parameters, which involves the choice of sowing dates and methods, sowing rates, seeding depth, and sowing s density (Casini et al., 2020; Gomes et al., 2023; Tyrus, 2023).

Therefore, a scientific field experiment was conducted in the Southend Steppe of Ukraine in order to determine the most effective planting density of grain amaranth adapted to specific soil and climatic conditions.

MATERIALS AND METHODS

In 2022, a two-factor field experiment was established on the field of LLC "Aisberg", located within the boundaries of the Velykymykhaylivka settlement community of the Rozdlininsky district of the Odesa region which is located in the conditions of the Danubian province of the Southern Steppe subzone of Ukraine.

2 varieties of amaranth of domestic selection were selected for research (Figure 2).

Figure 2. General view of amaranth plants in the flowering phase:
a - amaranth plants of the Kharkivs`kyi 1 variety;
b - amaranth plants of the Liera variety

Varieties are included in the Register of Plant Varieties Suitable for Distribution in Ukraine and have different purposes. The Kharkivs`kyi 1 variety has a universal purpose. The Liera variety has a grain purpose. Both varieties belong to the species *A. hypochondriacus*.

Experimental scheme:

Factor A – different varieties of amaranth:
a_1 – Kharkivs`kyi 1 (control);
a_2 – Liera.

Factor B – post-emergence plant density:
b_1 – 90 $\cdot 10^3$ plants/ha;
b_2 – 120 $\cdot 10^3$ plants/ha (control);
b_3 – 150 $\cdot 10^3$ plants/ha;
b_4 – 180 $\cdot 10^3$ plants/ha.

The experimental variants are placed in 3 replications using the split-plot method.

To establish the calendar sowing dates based on the climatic indicators of the zone and the biological characteristics of the crop, the meteorological method was used. The measuring and weighing method were used to determine the biometric parameters of plant growth and development.

Leaf mass ratio (LMR) is the ratio of leaf dry mass to the dry mass of the entire plant (g/g)

The mean values and standard errors were used to analyze the data. The regression statistics and analysis of variance (ANOVA) within Microsoft Excel 2010 were used to provide mathematical analyses.

All data were compared using Least Significant Difference (LSD) test at 5% probability level.

Immediately after harvesting the pre-crop (winter wheat), the soil was disked to a depth of 10-12 cm in two tracks. The dry post-harvest period did not require additional tillage before autumn plowing due to the absence of weeds. At the end of October, a moldboard plowing was carried out to a depth of 23-25 cm.

With the acquisition of physical ripeness of the soil in the spring, harrowing was carried out. After 2 weeks, with the appearance of early spring and perennial weeds, the first cultivation was carried out with harrowing to a depth of 10-12 cm. With the appearance of a new wave of weeds in the "white thread" phase, the field was harrowed and immediately before sowing, pre-sowing cultivation was carried out to a depth of 4-5 cm with followed by compaction.

Amaranth was sown to a depth of 2-3 cm in a wide-row method (row spacing 60 cm) with a seeding rate of 1 kg per hectare and followed compaction. Before and after the emergence of seedlings, harrowing was carried out.

The research program did not provide for the use of crop protection products from harmful organisms and the application of mineral fertilizers in connection with the production of organic amaranth.

Before the beginning of amaranth branching, manual weeding was carried out with the simultaneous formation of the crop density according to the experimental scheme.

After the formation of the planned crop density of amaranth in the experiment, inter-row cultivation was carried out.

Amaranth was harvested in a continuous manner in the phase of full ripeness of amaranth grain.

RESULTS AND DISCUSSIONS

The monitoring of weather conditions over the years of research indicates their certain diversity and impact on the formation of the amaranth grain yield in the experiment. It can certainly be stated that the 2021-2022 and 2022-2023 agricultural years were close to the average long-term indicators and were generally favorable for amaranth plants. The 2023-2024 agricultural year was extremely unfavorable for most agricultural crops, including amaranth, since higher temperature values and an extreme lack of precipitation were observed during the growing season, which in most cases were torrential in nature (Figure 3).

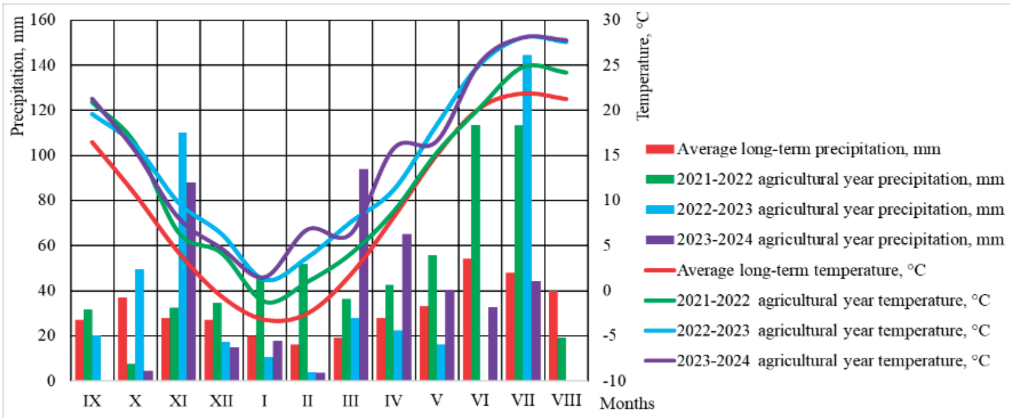

Figure 3. Monitoring of weather conditions over the research years

During 3 years of research, observations of the dynamics of the height of amaranth plants showed that the Liera amaranth variety, due to its genetic characteristics, was noticeably taller than the Kharkivs`kyi 1 variety (Table 1).

In the phase of full ripeness, at a post-emergence plant density of $120 \cdot 10^3$ plants/ha, amaranth plants in the control variant reached a height of 152 cm, while plants of the Liera variety at the same post-emergence plant density had an average height of 158 cm, which is 6 cm higher than the control indicators.

Plants of the Liera variety in the variant with $90 \cdot 10^3$ plants/ha were per 8 cm higher, in the variant with $150 \cdot 10^3$ plants/ha were per 3 cm higher and in the variant with $180 \cdot 10^3$ plants/ha were per 6 cm higher compared to similar indicators of variants with the Kharkivs`kyi 1 variety. However, it is also worth noting that the thickening of amaranth crops to some extent affects the height of the plants.

The highest height indicators were recorded at the highest post-emergence plant density of $180 \cdot 10^3$ plants/ha. For the Kharkivs`kyi 1 variety, the height of plants in the panicle formation phase was 86.0 cm, in the flowering phase it was 152.0 cm, and in the phase of full grain ripeness it was 164.0 cm. For the control variant with a post-emergence plant density of $120 \cdot 10^3$ plants/ha, these indicators were lower and were 80.0 cm, 147.0 cm and 152.0 cm, respectively, which were per 6.0, 5.0 and 12.0 cm less. At the same time, the lowest plant height was recorded at the lowest planting density of $90 \cdot 10^3$ plants/ha.

Table 1. Change in the height of amaranth plants during the growing season depending on the planting density

average for 2022-2024Variant of the experiment		Height of amaranth plants, cm					
Factor A, amaranth variety	Factor B, post-emergence plant density, plants/ha	Phase of panicle formation	Flowering phase	Grain full ripeness phase	Phase of panicle formation	Flowering phase	Grain full ripeness phase
					Average by factor B		
Kharkivs`kyi 1	$90 \cdot 10^3$	75	142	145	76	143	149
	$120 \cdot 10^3$ (control)	80	147	152	84	149	155
	$150 \cdot 10^3$	83	150	161	87	156	163
	$180 \cdot 10^3$	86	152	164	90	159	167
Average by factor A		81	148	156			
Liera	$90 \cdot 10^3$	77	144	153			
	$120 \cdot 10^3$	87	150	158			
	$150 \cdot 10^3$	90	162	164			
	$180 \cdot 10^3$	93	166	170			
Average by factor A		87	156	161			
*LSD_{05}, cm		A=1.989 B=1.216	A=3.951 B=0.783	A=0.762 B=1.111			

*LSD - Least Significant Difference

With an increase in the post-emergence plant density from 90 to $180 \cdot 10^3$ plants/ha, amaranth plants increased in height according to the development phases. For the Kharkivs`kyi 1 variety, for the period from the panicle formation phase to the flowering phase, the increase in plant height for the post-emergence plant density variants of $90 \cdot 10^3$; $120 \cdot 10^3$; $150 \cdot 10^3$ and $180 \cdot 10^3$ plants/ha was 67 cm, 67 cm, 67 cm and 66 cm, respectively. For the period from the flowering phase to the phase of full grain ripeness, these indicators were 3 cm, 5 cm, 11 cm and 12 cm, respectively. At the same time, for the Liera variety, for the period from the panicle formation phase to the flowering phase, the increase in plant height for the post-emergence plant density variants of $90 \cdot 10^3$; $120 \cdot 10^3$; $150 \cdot 10^3$ and $180 \cdot 10^3$ plants/ha was 67 cm, 63 cm, 72 cm and 73 cm, respectively. For the period from the flowering phase to the phase of full grain ripeness, these indicators were respectively at the level of 9 cm, 8 cm, 2 cm and 4 cm.

That is, for the Kharkivs`kyi 1 variety, regardless of the planting density, the increase in plant height was stable (66-67 cm) until the flowering phase, and from the flowering phase to full maturity phase this indicator increased slightly with thickening of the crops. For the Liera variety with thickening of the crops, this indicator increased from the panicle formation phase to the flowering phase, and from the flowering phase to the full maturity phase, on the contrary, it decreased.

During the growing season, the thickness of the stems of amaranth plants increases. However, the post-emergence plant density also has a certain effect on the thickness of the stems of amaranth plants (Table 2).

The greatest thickness of the stems of amaranth plants of both varieties was observed at a post-emergence plant density of $90 \cdot 10^3$ plants/ha. For the Kharkivs`kyi 1 variety, the thickness of the plant stems varied according to the development phases within the range from 2.5 to 3.0 cm. For the Liera variety, this indicator varied from 2.8 to 3.2 cm depending on the post-emergence plant density.

The smallest stem thickness was recorded at a post-emergence plant density of $180 \cdot 10^3$ plants/ha. For the Kharkivs`kyi 1 variety, it ranged from 2.0 (panicle formation phase) to 2.3 cm (full ripeness phase), and for the Liera variety, these indicators ranged from 2.1 to 2.7 cm.

Other options for post-emergence plant density for both varieties, which were studied in the experiment by the indicator of stem thickness, had an intermediate value. This can be explained by the fact that when the crops are thickened, the plants spend a significant amount of energy on increasing height, competing with each other for the receipt of light energy and were unable to form a thick and strong stem.

Table 2. Dynamics of changes in the stem thickness of amaranth plants during the growing season depending on the planting density, average for 2022-2024

Variant of the experiment		Stem thickness of amaranth plants, cm					
Factor A, amaranth variety	Factor B, post-emergence plant density, plants/ha	Phase of panicle formation	Flowering phase	Grain full ripeness phase	Phase of panicle formation	Flowering phase	Grain full ripeness phase
					Average by factor B		
Kharkivs`kyi 1	$90 \cdot 10^3$	2.5	2.7	3.0	2.7	2.9	3.1
	$120 \cdot 10^3$ (control)	2.4	2.7	2.8	2.5	2.7	2.9
	$150 \cdot 10^3$	2.3	2.5	2.5	2.2	2.3	2.7
	$180 \cdot 10^3$	2.0	2.1	2.3	2.1	2.2	2.5
Average by factor A		2.3	2.5	2.7			
Liera	$90 \cdot 10^3$	2.8	3.0	3.2			
	$120 \cdot 10^3$	2.5	2.6	3.0			
	$150 \cdot 10^3$	2.1	2.5	2.8			
	$180 \cdot 10^3$	2.1	2.3	2.7			
Average by factor A		2.4	2.6	2.9			
*LSD_{05}, cm		A=0.065 B=0.129	A=0.744 B=0.549	A=0.065 B=0.116			

*LSD - Least Significant Difference

From literary sources it is known that the rate of leaf formation, the total area of the photosynthetic surface and its productivity have a significant impact on yield, since 95% of the dry matter of the crop is formed from organic compounds.

The process of leaf formation in both varieties of amaranth occurs before the flowering phase, which accounts for the largest number of leaves per plant for all variants of post-emergence plant density in the experiment (Table 3). At the same time, plants of the Liera variety were characterized by greater leaf mass ratio (LMR) and at the peak of leaf formation this indicator was 0.267-0.281 (g/g) depending on the post-emergence plant density, while in the Kharkivs`kyi 1 variety it was only 0.232-0.253 (g/g).

Table 3. Change in leaf mass ratio of amaranth plants during the growing season depending on crop density, average for 2022-2024

Variant of the experiment		Leaf mass ratio, g/g					
Factor A, amaranth variety	Factor B, post-emergence plant density, plants/ha	Phase of panicle formation	Flowering phase	Grain formation phase	Phase of panicle formation	Flowering phase	Grain formation phase
					Average by factor B		
Kharkivs`kyi 1	$90 \cdot 10^3$	0.155	0.246	0.190	0.155	0.260	0.208
	$120 \cdot 10^3$ (control)	0.163	0.249	0.190	0.163	0.263	0.211
	$150 \cdot 10^3$	0.169	0.253	0.197	0.169	0.267	0.215
	$180 \cdot 10^3$	0.141	0.232	0.183	0.134	0.249	0.201
Average by factor A		0.157	0.245	0.190			
Liera	$90 \cdot 10^3$	0.155	0.274	0.225			
	$120 \cdot 10^3$	0.162	0.277	0.232			
	$150 \cdot 10^3$	0.169	0.281	0.232			
	$180 \cdot 10^3$	0.127	0.267	0.218			
Average by factor A		0.153	0.275	0.227			
*LSD_{05}, cm		A=0.00234 B=0.00113	A=0.00065 B=0.00093	A=0.00300 B=0.00105			

*LSD - Least Significant Difference

In addition, as the conducted studies have shown, with an increase in the amaranth post-emergence plant density from $90 \cdot 10^3$ to $150 \cdot 10^3$ plants/ha, the LMR during the growing season initially increases, but at the highest post-emergence plant density ($180 \cdot 10^3$ plants/ha) it begins to decrease. This indicates that to achieve maximum LMR, the optimal planting density was $150 \cdot 10^3$ plants/ha for both of varieties.

As the analysis of variance result, the share of the factors influence on the amaranth plants growth processes was determined (Figure 4). It was established that the greatest influence (71.4%) on the growth processes of amaranth plants is exerted by factor B (post-emergence plant density).

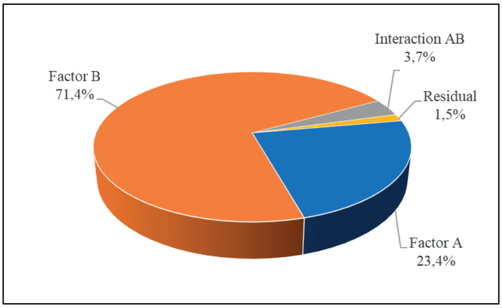

Figure 4. The share of influence of factors on the growth processes of amaranth plants

It was established that there is a weak correlation between the height of amaranth plants and Leaf mass ratio (Figure 5).

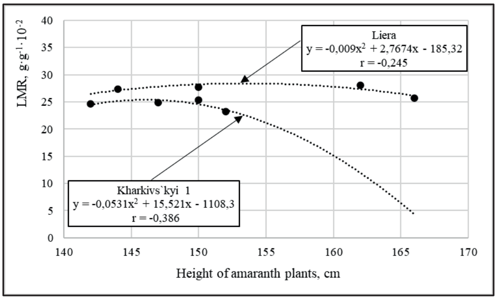

Figure 5. Correlation-regression models of the dependence of the LMR and height of amaranth plants in the flowering phase

The correlation coefficient between the height of amaranth plants and their leafiness for the Kharkivs`kyi 1 variety was r = -0.386, and for the Liera variety it was r = -0.245. Analysis of correlation-regression models shows that with an increase of the planting density to $150 \cdot 10^3$ plants/ha, the plants height increased with a simultaneous LMR increase. With further thickening of crops to $180 \cdot 10^3$ plants/ha, amaranth plants begin to compete with each other for the main factors of plant life, including the factor of light energy, which leads to an increase in plant height and simultaneous drying of the leaf's lower tiers.

CONCLUSIONS

Over the years of research, observations of the dynamics of amaranth plant height showed that the Liera amaranth variety was noticeably taller than the Kharkivs`kyi 1 variety. Thus, in the Kharkivs`kyi 1 variety in the phase of full ripeness, at a post-emergence plant density of $120 \cdot 10^3$ plants/ha (control), amaranth plants reached a height of 152 cm, while plants of the Liera variety at the same post-emergence plant density had an average height of 158 cm, which was per 6 cm higher.

The highest indicators of amaranth plant height were recorded at the highest post-emergence plant density ($180 \cdot 10^3$ plants/ha). Thus, for the Kharkivs`kyi 1 variety, the plant height in the panicle formation phase was 86.0 cm, in the flowering phase it was 152.0 cm, and in the phase of full grain ripeness it was 164.0 cm, while for the Liera variety, in the same phases the plants were higher by 7 cm 14 cm and 6 cm, respectively. At the same time, the lowest plant height for both varieties were recorded at the lowest ($90 \cdot 10^3$ plants/ha) post-emergence plant density of amaranth plants.

The greatest stem thickness was observed at a post-emergence plant density of $90 \cdot 10^3$ plants/ha and for the Kharkivs`kyi 1 variety it varied from 2.5 to 3.0 cm according to the development phases, and for the Liera variety this indicator ranged from 2.8 to 3.2 cm. The smallest stem thickness was recorded for both varieties at post-emergence plant density of $180 \cdot 10^3$ plants/ha and for the Kharkivs`kyi 1 variety it was in the range from 2.0 to 2.3 cm, and for the Liera variety it was in the range from 2.1 to 2.7 cm according to the development phases.

The greatest values of LMR were at a seeding density of $150 \cdot 10^3$ plants/ha. For the Kharkivs`kyi 1 variety, this indicator was 0.197 g/g, and for the Liera variety it was 0.232 g/g. To ensure the best conditions for plant growth and development, the optimal seeding density is $150 \cdot 10^3$ plants/ha.

The obtained results contribute to the optimization of the amaranth sowing complex in the Southern Steppe of Ukraine, which allows obtaining high permanent yields of this crop.

ACKNOWLEDGEMENTS

This research work was carried out with the support of Institute of Climate Smart Agriculture of the National Academy of Agrarian Sciences of Ukraine and Odesa State Agrarian University.

REFERENCES

Adhikary, D., Khatri-Chhetri, U., Slaski, J. (2020). Amaranth: an ancient and high-quality wholesome crop. Nutritional value of Amaranth. Intech Open. https://doi.org/10.5772/intechopen.88093

Casini, P., Biancofiore, Gh. (2020). Optimizing sowing time for boosting productivity and nutritional quality of amaranth (*Amaranthus cruentus* L.) genotypes under Mediterranean climate. *Acta agriculturae Slovenica,* 115(1), 1228. https://doi.org/10.14720/aas.2020.115.1.1228

Dudka, M.I. (2019). Cultivation of Amaranth paniculatus (Amaranthus paniculatus) in the northern steppe of Ukraine. *Cereals,* 3(1), 52-61. https://doi.org/10.31867/2523-4544/0060

Gomes, V. E. D. V., Lindsey, L. E., Mesquita, R. O. (2023). Effect of soil type and sowing depth on the germination and early growth of two grain amaranth cultivars. *Agrosystems, Geosciences & Environment*, 6(3), e20386. https://doi.org/10.1002/agg2.20386

Hoptsii, T.I. Voronkov, M.F., Bobro, M.A., Miroshnychenko, L.O., Lymanska, S.V., Hudym, O.V., Hudkovska, N.B., Duda, Yu.V. .(2018). Amaranth: breeding, genetics and cultivation prospects: monograph. Kharkiv: KhNAU.

Idowu-Agida, O.O., Oladosu, B.O., Olaniyi, J.O. (2020). Evaluation of yield and yield related traits of exotic grain amaranth (*Amaranthus* spp.) accessions. *Journal of Tropical Agriculture, Food, Environment and Extension,* 19(1), 11-17. https://doi.org/10.4314/as.v19i1.2

Joshi, D. C., Sood, S., Hosahatti, R., Kant, L., Pattanayak, A., Kumar, A., Yadav, D., Stetter, M.G.(2018). From zero to hero: the past, present and future of grain amaranth breeding. *Theoretical and Applied Genetics*, 131, 1807-1823. https://doi.org/10.1007/s00122-018-3138-y.

Levchuk, I.V., Kishchenko, V.A., Timchenko, V.K., Kunitsa, K.V. (2015). Amaranth oil - the quality and safety of the use in a dietary supplement. *Integrated technologies and energy saving,* 2, 74-81. Retrieved December 19, 2024 from https://repository.kpi.kharkov.ua/server/api/core/bitstreams/2e4bdae2-a54d-4e8f-853c-b857599badf0/content

Malik, M., Sindhu, R., Dhull, S., Bou-Mitri, C.,Singh, Yu., Panwar, Sh., Khatkar B.S. (2023). Nutritional composition, functionality, and processing technologies for amaranth. *Journal of Food Processing and Preservation*, (1), 1753029. https://doi.org/10.1155/2023/1753029

Mambetova, N. K., Sultanova, Z. S. (2022). Methods of developing agrotechnology of amaranth plant under organic farming conditions. *Theoretical & Applied Science*, (9), 163-168. https://doi.org/10.15863/TAS.2022.09.113.31

Pelech, L. (2021). Influence of cultıvatıon methods on the formatıon of ındıvıdual productıvıty of amaranth. *Sciences of Europe,* 67(2), 21-27. https://doi.org/10.24412/3162-2364-2021-67-2-21-27.

Silva, J., Bianchini, A., Costa, P., Lobo, F. de A., Moreira de Almeida J.P., Moraes M.F. (2019). Amaranth response to water stress. *Journal of Experimental Agriculture International,* 40(1), 1–9. https://doi.org/10.9734/JEAI/2019/v40i130356

Sots, S., Kustov, I., Lapinska, A., Kotsiuk, A., Chehlatoniev, V. (2024). Amaranth: problems and perspectives of processing. *Grain Products & Mixed Fodder's*, *24* (2). https://doi.org/10.15673/gpmf.v2024i2.2815

Stankevych, G., Valentiuk, N., Ovsiannykova, L., Zhygunov,D. (2021). Changes in quality of amaranth grain in the course of postharvest handling and storage. *Food science and technology,* 15(1), 80-90.https://doi.org/10.15673/fst.v15i1.1959

Tyrus, M. (2023). Influence of sowing time on grain yield of amaranth of the Western Forest-Steppe of Ukraine. *Scientific Progress & Innovations*, *26* (4), 71-76. https://doi.org/10.31210/spi2023.26.04.13

Tyrus, M., Lykhochvor, V., Dudar, I., Stefaniuk, S., Andrushko, O.(2023). Amaranth yield depending on the sowing rate. *Scientific Horizons,* 26 (8), 33-41. https://doi.org/10.48077/scihor8.2023.33

Valentiuk, N., Stankevych, G. (2020). Peculiarities of the process of purification of amarant grain from impurities. *Grain Products and Mixed Fodder's*, 20(3), 10-19. https://doi.org/10.15673/gpmf.v20i3.1844

Weerasekara, A., Waisundara, V.Y. (2020). Amaranth as a pseudocereal in modern times: Nutrients, taxonomy, morphology and cultivation. *Sri Lanka: Australian College of Business & Technology.* https://doi.org/10.5772/intechopen.90927

Yaniuk, T., Hriunvald, N. (2022). Amaranth production in Ukraine: State and prospects. *Food resources,* 10(18), 179-192. https://doi.org/10.31073/foodresources2022-18-18