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PLANTING PERIODS AND SCHEMES INFLUENCE THE YIELD-RELATED TRAITS AND OIL CONTENT OF AMARANTH (*AMARANTHUS VIRIDIS* L.) IN UZBEKISTAN

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SUMMARY

Uzbekistan's local market presently sells mainly imported vegetable oil. However, the oil network has huge production capacity in covering a massive demand in Uzbekistan. The implementation of comprehensive measures progresses to develop the oil industry to increase production volumes and enhance finished products to meet population needs. Field experiments on amaranth's (*Amaranthus viridis* L.) three cultivars (Gultojixo'roz "IKBA-TDAU 1", and Giant) under typical gray soils of Uzbekistan showed that earlier sowing (April 10) with both planting schemes (70 cm × 15 cm and 70 cm × 25 cm) ensured better growth, phenological traits, and yield-related traits than late sowing (April 20). In the first planting period, grain yield exceeded the control by 0.16–0.4 t/ha, and 1000-grain weight was also higher. Amaranth seeds appeared to contain valuable bioactive compounds, including squalene, tocotrienols, omega-3, 6, and 9 fatty acids, proteins, and vitamins. The oil content ranged from 9.5% to 12.6%, depending on the amaranth cultivar, and the cultivars Gultojixo'roz "IKBA-TDAU 1" and Giant showed the highest oil content. The results highlighted amaranth's potential as a source of oil, proteins, carbohydrates, and vitamins for use in food, pharmaceutical, and cosmetic industries.

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Keywords: Amaranth (*A. viridis* L.), cultivars, planting period, planting scheme, yield-related traits, oil content, bioactive compounds, proteins, carbohydrates, vitamins

Key findings: Amaranth (*A. viridis* L.) with early sowing and planting schemes (70 cm × 15 cm and 70 cm × 25 cm) showed enhanced growth, phenology, and grain yield compared with late sowing. Amaranth seeds contained 9.5%–12.6% oil along with bioactive compounds. Cultivars Gultojixo'roz "IKBA-TDAU 1", and Giant demonstrated superior grain yield and seed oil contents.

INTRODUCTION

The world's population rapidly increases by an average of 80 million people per year, and by 2025, it could reach eight billion. In this context, the Uzbekistan population grows annually by 650,000–670,000 people, and it may reach above 38 million by 2026. This trend reveals a sharp rise in the demand for agricultural food products, both globally and nationally (Adaptation *et al.,* 2020). According to forecasts, by 2030 the demand for food will increase by 50%, and by 2050, agricultural production will need to rise by 60% versus the 2006 levels to meet the global population's nutritional requirements (Adhikary *et al.,* 2020*;* Allanov *et al.,* 2021; Gins *et al.,* 2022). Past studies demonstrated the crucial role of the cultivation of grain, leguminous, and forage crops in crop rotation systems. These include improving soil melioration, preventing wind and water erosion, enriching soils with organic matter, and enhancing soil agrophysical, mechanical, and biological properties (Artamonov *et al*., 2013; Gins *et al.,* 2024).

Within the framework of agricultural reforms in Uzbekistan, rational land use, soil fertility preservation and improvement, and the provision of both flour products for the population and protein-rich forage for livestock have become urgent priorities. In this regard, the introduction of amaranth (*Amaranthus viridis* L.) into crop rotation systems with cereals has provided opportunities for obtaining ecologically clean products while simultaneously meeting feed demands (Armor, 1979*)*. The establishment of livestock-breeding complexes, particularly in arid and mountainous regions of Uzbekistan, highlights the importance of intensification in providing high-quality forage, including the cultivation of feed crops in natural pastures and hayfields. Similarly, maintaining, restoring, and enhancing soil fertility remain as the most pressing challenges in the agricultural sector of the Republic.

Amaranth is a currently recognized staple food source worldwide due to its high nutritional value. Studies have shown its protein content surpasses that of most plant-based food crops. The number of amaranth-producing countries is steadily increasing its production each year (Olowoake, 2014; Temel and Keskin*,* 2023; Po'latov, 2023; Gins *et al.,* 2024). In Uzbekistan, amaranth is typically an ancient crop, and in previous years, it has regained popularity as a highly beneficial and promising plant, yielding abundant harvests (Petruzzello, 2016; Charshanbiyev *et al*., 2022; Gins *et al.,* 2022).

Belonging to the family Amaranthaceae, amaranth is an annual herbaceous plant reaching 2–3 m in height, with stems 8–10 cm thick. Amaranth leaves are elongated and elliptical, alternately arranged, while its flowers are small and inconspicuous, forming broom-like clusters up to half a meter long. The seeds are small, spherical, and brown to yellow, weighing 0.4–0.6 g per 1000 seeds. A single amaranth plant is capable of producing up to 0.5 kg of seeds (Charshanbiyev *et al.,* 2023).

Amaranth grain contains phytochemicals, such as polyphenols, saponins, tannins, and oxalates. Based on the phytochemicals, the economic and medicinal significance of amaranth is exceptionally high. In particular, the amaranth seed oil has emerged to be effective in cleansing the body of radionuclides and heavy metals, as well as being used in the treatment of infectious diseases, diabetes, liver disorders,

Table 1. Experimental design used in the study.

Variants	Sowing date	Amaranth cultivars	Planting scheme (cm)	Sowing depth	Theoretical plant population per hectare (plants ha^{-1})
1 (Control)	April 10	Gultojixo'roz "IKBA-TDAU 1"	70 × 15	1.0 cm	95238
2			70 × 25	1.5 cm	57143
3	April 20	Gultojixo'roz "IKBA-TDAU 1"	70 × 15	1.0 cm	95238
4			70 × 25	1.5 cm	57143
5	April 10	Giant	70 × 15	1.0 cm	95238
6			70 × 25	1.5 cm	57143
7	April 20	Giant	70 × 15	1.0 cm	95238
8			70 × 25	1.5 cm	57143

cardiovascular conditions, and gastrointestinal ulcers. The presence of squalene, a valuable compound to the pharmaceutical industry, has significantly increased scientific and commercial interest in amaranth seed oil. Historically, the extraction of squalene comes from shark and whale liver; however, the presented research has demonstrated that amaranth oil contains up to 8% squalene compared with only 0.7% in olive oil (Garcia and Aguira*,* 2019; Weerasekara and Waissundara*,* 2020). Moreover, amaranth oil is rich in unsaturated fatty acids, tocopherols (vitamin E), phytosterols, rutin, and other biologically active compounds, which contribute to its antioxidant, antimicrobial, and therapeutic properties.

Since 2013, specialized studies have progressed on amaranth under the initiative of the Science and Technology Development Coordinating Committee in Uzbekistan. Local and foreign cultivars have undergone evaluation, with the most productive genotypes identified. Using cold-pressing technology from the German company "AEN Engineering GmbH & Co. KG," the oil extraction occurs from locally cultivated amaranth grains, which proved to contain the highest levels of squalene and other beneficial bioactive compounds. Comparative analysis confirmed the biological value of amaranth oil is approximately twice that of sea buckthorn oil (Artamonov *et al*., 2013; Gins *et al*., 2024).

Currently, amaranth's importance is growing in both national and international markets. The prospects of exporting amaranth seeds, flour, leaves, roots, and oil as valuable nutritional and pharmaceutical products have increased. Therefore, expanding the cultivation of amaranth and exploring its potential as a multifunctional crop for food security, animal husbandry, and the pharmaceutical industry remains a highly relevant scientific and practical task in Uzbekistan.

MATERIALS AND METHODS

The experiment on amaranth (*A. viridis L.),* conducted during 2023–2024, was under typical loose, gray soil conditions at the Research Institute of Plant Science and Genetic Resources and the Tashkent State Agrarian University, Tashkent, Uzbekistan (Table 1). The study, aimed at assessing the grain composition of amaranth, was reliant on field experiments, with the humidity level determined following the "Methodology of Field Experiments" (Dospekhov, 1985). Three cultivars of amaranth, such as Gultojixo'roz "IKBA-TDAU 1", and Giant, obtained cultivation under the usual gray soil conditions. Furthermore, the analysis of grain composition and fat content of amaranth followed standard procedures.

Traits measurement

Morphological traits entailed recording to evaluate the performance of the cultivars under gray soil conditions. The measurements included plant height (cm), number of leaves per plant, panicle length (cm), panicle fresh weight (g), and grain yield per plant (g), gathered at the flowering and maturity stages. The biochemical traits determination of amaranth grains also succeeded. Protein content estimation used the Kjeldahl method, while oil and vitamin contents' analysis depended on standard analytical procedures commonly employed in plant biochemical studies. All measurements had replicates, with the data obtained subjected to statistical analysis to ensure the reliability and accuracy of cultivar comparisons.

Oil extraction

The process of extracting oil from amaranth plant seeds transpired in laboratory conditions by following the protocol in the BIOBASE FH1200 (X) SOXHLETTE apparatus at the Scientific Research Institute of Plant Science and Genetic Resources, Tashkent, Uzbekistan. The weighing of 100 g of amaranth plant seeds continued on a laboratory scale. The resulting seed, when ground into powder, used liquid nitrogen. The finished sample proceeded to its placement in an envelope made of filter paper before sealing and placing in a metal mesh. The mass of metal blocks in the alcohol separator attained measurement on a laboratory scale. The 60 g of 96% alcohol entailed pouring into the measured bottles. The bag's strengthening occurred by placing it on the apparatus and a metal grid placed on top of it. In this process, placing one plant reached three returns. Putting the six samples in the apparatus achieved being fixed. Before starting the device, turning on the water received inspection in compliance with all technical regulations. The device timer's setting was for four hours, with monitoring occurring during these hours. This process had the alcohol boiled off. As a result, a combination of alcohol and oil was evident in the vehicle. The obtained samples incurred stirring again for another two hours. This process separated the alcohol, and the oil remains in the bag by itself. Obtaining the mass of the oil involved weighing it again on a laboratory scale. The average of three samples succeeded its calculation, then converted to a percentage. In the recently studied literature, it showed the oil level of amaranth seeds was 11%. According to the presented results, the oil level of the amaranth seeds was 11%–12%. In addition to the above research, determining the chemical composition of the amaranth plant seeds also ensued.

Statistical analysis

The oil content of amaranth seeds reached evaluation from three replications for each cultivar based on the yield obtained from 10 g of seeds. The results indicated significant variation among the cultivars as well as between replications. For Gultojixo'roz "IKBA-TDAU 1", the oil yield varied from 0.98 to 1.25 g, averaging 1.16 g (≈11.6%). In the case of the Giant cultivar, the oil content ranged between 1.04 and 1.25 g, with an average of 1.15 g (≈11.5%).

The analysis revealed the following results for Gultojixo'roz "IKBA-TDAU 1", and Giant, showing relatively stable but lower levels of oil accumulation, averaging around 11%–12%. Standard deviation and mean values acquired calculations to assess variability, and differences among cultivars were statistically significant at $p < 0.05$ according to the Methodology of Field Experiments (Dospekhov, 1985).

RESULTS AND DISCUSSION

Results of morphological and yield characteristics

Field experiments on amaranth (*Amaranthus viridis* L.) happened with two different planting periods and two planting schemes under typical gray soil conditions of Tashkent Region, Uzbekistan. In amaranth cultivars Gultojixo'roz "IKBA-TDAU 1" with early planting (April 10) and planting scheme (70 cm × 15 cm), the plant height was 175 cm in the control variant. However, the plant height expressed enhancement (195 cm) with planting in the first term (April 10) and planting scheme of 70 cm × 25 cm (Table 2). In the second planting period (April 20) with a planting scheme of 70 cm × 15 cm, the cultivars Gultojixo'roz IKBA-TDAU 1" plants appeared to be 168 cm tall.

Table 2. Morphological and yield traits of amaranth cultivars in the integration of planting period and scheme.

No.	Variants (cultivar name + planting date and planting scheme)	Plant height (cm)	Seedling density (units ha^{-1})	Furrow weight (g)		Grain weight in one bag (g)	1000-grain weight (g)
				Wet	Dry		
1	Control, Gultojixo'roz "IKBA-TDAU 1", April 10, 70 × 15	175	89228	323.5	81.2	28.6	4.6
2	Gultojixo'roz "IKBA-TDAU 1", April 10, 70 × 25	195	51113	532.2	124.6	54.6	5.8
3	Gigant, April 10, 70 × 15	180	92282	459.4	110.5	32.3	4.5
4	Gigant, April 10, 70 × 25	192	53133	519.3	112.6	51.5	5.7
5	Gultojixo'roz "IKBA-TDAU 1", April 20, 70 × 15	168	84318	313.7	89.2	27.7	4.4
6	Gultojixo'roz "IKBA-TDAU 1", April 20, 70 × 25	179	56035	502.8	117.8	42.9	5.3
7	Gigant, April20, 70 × 15	171	93192	427.4	107.6	27.1	4.9
8	Gigant, April20, 70 × 25	178	54056	489.6	110.8	41.7	5.2

For the second period (April 20) with the planting scheme (70 cm × 25 cm), the plant height rose (179 cm). In the cultivar Giant during the first planting period (April 10) and planting scheme (70 cm × 15 cm), the plant height was 180 cm, and with the same planting period but different planting scheme (70 cm × 25 cm), an increased plant height (192 cm) was visible. In the second planting period (April 20) and planting scheme of 70 cm × 15 cm, the cultivar Giant showed a plant height of 171 cm, while with the planting scheme (70 cm × 25 cm), the said cultivar provided an increased plant height (178 cm).

These results demonstrate that wider spacing consistently increased plant height, while early sowing enhanced vegetative growth. Reports of similar observations came from Alemayehu *et al*. (2021), who also stated that reduced competition improves height and biomass, while early sowing supports better growth performance.

By planting the amaranth cultivar "IKBA-TDAU 1" in the control option with the first planting period (April 10) and a planting scheme (70 cm × 15 cm), the grain weight per plant was 28.6 g, but it increased to 54.6 g with a planting scheme of 70 cm × 25 cm (Table 2). In the same cultivar, during the second sowing period (April 20) and the planting scheme (70 cm × 15 cm), the grain weight per plant decreased (27.7 g). For cultivars Gultojixo'roz "IKBA-TDAU-1" with a planting scheme of 70 cm × 25 cm, the grain weight per plant increased (42.9 g). In the amaranth cultivar Giant for the first planting term (April 10) and planting scheme (70 cm × 15 cm), the grain weight per plant was 32.3 g, and with the same planting period at a planting scheme of 70 cm × 25 cm, the enhanced grain weight per plant (51.5 g) emerged. Moreover, in the amaranth cultivar Giant with the second planting period (April 20) and the planting scheme (70 cm × 15 cm), the grain weight per plant was 27.1 g, while with a planting scheme of 70 cm × 25 cm, the grain weight per plant increased to 41.7 g.

The obtained results demonstrate that planting time and planting scheme significantly affect grain weight per plant in different amaranth cultivars. In the cultivar "IKBA-TDAU 1", the highest grain weight per plant (54.6 g) was apparently with early sowing (April 10) and a wider spacing (70 cm × 25 cm), while delayed sowing (April 20) with a closer spacing (70 cm × 15 cm) reduced grain weight (27.7 g). Similarly, in the cultivar Giant, the maximum grain weight (51.5 g) occurred with early sowing and a wider spacing, whereas reduced values (27.1 g) were evident with late sowing and a closer spacing. Thus, our results support earlier findings and indicate that under the gray soil conditions of Uzbekistan, early sowing combined with a wider spacing (70 cm × 25 cm) is the most effective strategy to increase grain weight per plant in amaranth cultivars. These results confirmed early sowing and wider spacing significantly increased the grain weight**,** which was consistent with past findings (Rastogi and Shukla, 2013; Alemayehu *et al*., 2021). Previous studies also emphasized optimized sowing and spacing enhanced the yield and nutritional quality of amaranths (He *et al*., 2002; Martirosyan *et al*., 2007).

The results revealed sowing times and planting schemes have a cumulative effect on the grain yield of the amaranth cultivars. According to the results, in amaranth cultivars Gultojixo'roz "IKBA-TDAU 1" with the first sowing period (April 10) and the planting scheme (70 cm × 15 cm), the 1000-grain weight was 4.6 g (Table 2). In the same cultivars, with the planting period (April 10) and a planting scheme of 70 cm × 25 cm, the 1000-grain weight rose (5.8 g). During the second sowing period (April 20) and planting scheme (70 cm × 15 cm), the 1000-grain weight was 4.4 g in the cultivars Gultojixo'roz "IKBA-TDAU 1". However, in the same cultivars with a planting scheme of 70 cm × 25 cm, the 1000-grain weight increased (5.3 g). In the cultivar Giant, by planting in the first period (April 10) with the planting scheme (70 cm × 15 cm), the 1000-grain weight was 4.5 g. But, with the same sowing period and a planting scheme of 70 cm × 25 cm, it expressed an enhanced 1000-grain weight (5.7 g). In the cultivar Giant with the second sowing term (April 20) and planting scheme (70 cm × 15 cm), the 1000-grain weight was 4.9 g, and the same cultivar with a planting scheme of 70 cm × 25 cm showed an increased 1000-grain weight (5.2 g).

Previous studies have shown sowing dates and plant spacing play a crucial role in determining seed weight and grain quality in amaranths. According to Svirskis (2003), wider spacing allows for improved seed filling, which results in a higher 1000-grain weight due to better access to light and soil nutrients. Similarly, Mlakar *et al*. (2010) reported earlier sowing generally supports better physiological development of amaranth seeds than delayed planting, which often reduces seed mass and yield stability.

Study findings are consistent with these earlier reports, as early sowing (April 10) combined with a wider spacing (70 cm × 25 cm) resulted in an enhanced 1000-grain weight in both cultivars. This suggests that under the gray soil conditions of Uzbekistan, careful management of planting time and spacing is essential to maximize grain quality and yield in amaranths.

The growing season of the amaranth occurred to be a little longer (150–160 days) under the environmental conditions of Uzbekistan. Amaranth takes 7–10 days for the seeds to germinate. It was evident that it takes 60–70 days for bud formation and flowering and 70–90 days for harvesting and ripening. According to the results, the detection of the amaranth grain yield was successful, and with the first sowing term (April 10) and planting scheme (70 cm × 15 cm), the cultivar Gultojixo'roz "IKBA-TDAU 1"s grain yield in the control option was 2.58 t/ha (Table 3). However, the same amaranth cultivar with the first sowing time (April 10) and a planting scheme of 70 cm × 25 cm revealed an increased grain yield (2.79 t/ha). In the second sowing term (April 20) with the planting scheme (70 cm × 15 cm), the cultivars Gultojixo'roz "IKBA-TDAU 1" resulted in a grain yield of 2.40 t/ha, and with the planting scheme (70 cm × 25 cm), the enhanced grain yield (2.61 t/ha) emerged. The amaranth cultivar Giant with the first sowing period (April 10) and planting scheme (70 cm × 15 cm) gave a grain yield of 2.74 t/ha; however, with the same sowing period and a planting scheme of 70 cm × 25 cm, the grain yield further increased (2.98 t/ha). With the second sowing period (April 20) and the planting scheme (70 cm × 15 cm), the amaranth cultivar Giant resulted in a grain yield of 2.17 t/ha, and the same cultivar with a planting scheme of 70 cm × 25 cm showed an increased grain yield (2.44 t/ha). Amaranth cultivars with the planting time (April 10) and planting scheme (70 cm × 25 cm) showed elevated yields; however, the growing period was much longer.

Table 3. Agronomic and yield-related traits of amaranth cultivars in the integration of planting period and scheme.

No.	Variants (cultivar name + planting date and planting scheme)	Seedling density (units ha^{-1})	Grain weight per plant (g)	1000-grain weight (g)	Productivity (t ha^{-1})
1	Control, Gultojixo'roz "IKBA-TDAU 1", April 10, 70 × 15	89228	28.6	4.6	2.58
2	Gultojixo'roz "IKBA-TDAU 1", April 10, 70 × 25	51113	54.6	5.8	2.79
3	Gigant, April 10, 70 × 15	92282	32.3	4.5	2.98
4	Gigant, April 10, 70 × 25	53133	51.5	5.7	2.74
5	Gultojixo'roz "IKBA-TDAU 1", April 20, 70 × 15	84318	27.7	4.4	2.34
6	Gultojixo'roz "IKBA-TDAU 1", April 20, 70 × 25	56035	42.9	5.3	2.40
7	Gigant, April20, 70 × 15	90192	27.1	5.1	2.44
8	Gigant, April20, 70 × 25	52056	41.7	5.2	2.17

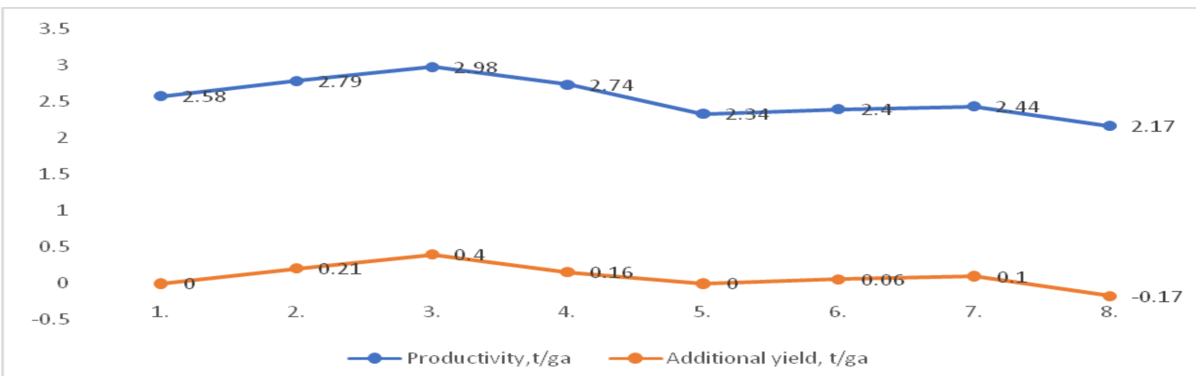

Figure 1. Agronomic and yield-related traits of amaranth cultivars in the integration of planting period and scheme.

The study results showed both sowing time and planting scheme significantly affected the grain yield of amaranths under gray soil conditions of Uzbekistan. Early sowing and wider spacing consistently enhanced yield performance across cultivars. Similar findings came from Mlakar *et al*. (2010), who observed earlier sowing improved yield stability and productivity through better utilization of the growing season. Likewise, Rana *et al.* (2017) emphasized wider spacing reduces interplant competition, improves resource allocation, and enhances per-plant yield. Kauffman and Weber (1990) also noted the amaranth requires a relatively long growing period, and timely sowing ensures favorable conditions during flowering and grain filling. In our study, the growing season extended to 150–160 days, and early sowing (10 April) combined with wider spacing (70 cm × 25 cm) consistently produced the highest grain yield in both cultivars. Overall, these results indicate that the integration of proper sowing dates and wider spacing is an effective agronomic practice to maximize the yield potential of the amaranth under Uzbekistan's gray soil conditions.

Results of seed oil analysis

Seed oil content evaluation was successful in three amaranth cultivars: Gultojixo'roz "IKBA-TDAU 1", and Giant (Table 4). In "IKBA-TDAU 1", oil content varied between 9.8% and 12.5%,

Table 4. Oil content of amaranth cultivars' seeds.

No.	Amaranth cultivars	Repetitions	Oil obtained from 100 g seeds (g)	Oil content (%)
1		1	9.809	9.8
2	Gultojixo'roz "IKBA-TDAU 1"	2	12.408	12.4
3		3	12.532	12.5
Means			11.483	11.5
4		1	10.424	10.4
5	Giant	2	12.582	12.6
6		3	11.424	11.4
Means			11.477	11.5

while in Giant, it ranged from 10.4% to 12.6%. These levels align with, or slightly exceed, earlier reports of 6%–8%, with occasional values up to 12%, depending on the genotype and the environment (He *et al.,* 2002). Such results suggest favorable agro-climatic conditions in Uzbekistan, combined with the genetic potential of the studied cultivars. In addition to lipids, amaranth grains appeared to contain vitamins A, β-carotene, C, thiamine, riboflavin, and niacin, confirming earlier reports of amaranth's nutraceutical properties (Bejosano and Corke, 1998; Rastogi and Shukla, 2013).

The health benefits of the amaranth oil, particularly in cholesterol reduction and cardiovascular protection, have also gained documentation (Martirosyan *et al*., 2007; Gins *et al.,* 2024). Overall, "IKBA-TDAU 1" and Giant demonstrated the highest oil percentages and favorable nutrient composition, underlining amaranth's dual potential as a source of high-quality edible oil and functional food components.

CONCLUSIONS

Field experiments on amaranth (*A. viridis* L.) cultivars (Gultojixo'roz "IKBA-TDAU 1", and Giant [Russian]) showed earlier sowing with both planting schemes, ensuring better growth, phenological traits, and yield components than late sowing. In the first period, grain yield exceeded the control by 0.16–4.0 t/ha, while the 1000-grain weight was also higher. Oil content ranged from 9.5% to 12.6%, depending on the variety. Amaranth seeds emerged to contain valuable bioactive compounds. The results highlighted the amaranth's potential as a source of oil, proteins, carbohydrates, and vitamins for use in food, pharmaceutical, and cosmetic industries.

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