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Qualitative Composition of Amaranth Plants Depending on the Altitude Zone of Mountains and Foothills

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QUALITATIVECOMPOSITIONOFAMARANTHPLANTSDEPENDINGONTHEALTITUDEZONEOFMOUNTAINSANDFOOTHILLS

Strictly as per the compliance and regulations of:

Qualitative Composition of Amaranth Plants Depending on the Altitude Zone of Mountains and Foothills

Bekuzarova S. A. [α], Kuznetsov, I. Yu. [σ] & Dzampaeva M. V. [ρ]

Abstract- Amaranth is a multifunctional culture that surpasses many others by the amount of high-grade protein, vitamins, macro- and microelements from a unit of sown area. Amaranth grains (mature seeds) contain 14-18% of protein, up to 8% of oil, about 7% of N-free extractives and up to 4% of ash. It is used as dietary cereal, for the production of baby food, medical products, in the bakery and confectionery industries, as well as in feed production. Amaranth protein in its amino-acid composition approaches the ideal protein. Amaranth protein concentrates are not inferior to soy ones. Leaves of amaranth of vegetable cultivars are used for preparing salads, soups, fried, baked, boiled and dried food products. The green mass of amaranth is a valuable feed for pigs, cattle and other animals rich in proteins and vitamins.

In order to study the biological characteristics of amaranth in the mountain and piedmont zones of the Northern Caucasus, three species of the amaranth were sown for the first time: fodder (Amaranthus caudatus L.), grain (Amaranthus cruentus L.) and ornamental (Amaranthus hipochondriacus L.) ones. Taking into account the biological characteristics of amaranth, we studied its qualitative characteristics in contrasting conditions of growth of mountains and foothills. It was shown that, due to a number of biological features, amaranth seedlings in high mountains appear 7 days earlier than in the foothills and plants undergo a full development cycle. The difference between the species of amaranth depending on the altitude was revealed. The leaf area and the height of amaranth plants increase with increasing elevation above sea level, which positively affects the growth of biomass. In the conditions of high altitude the amount of pigments of the photosynthetic apparatus, vitamins, and carotene increases by 1.5–2 times. The studied species of amaranth (grain, fodder, decorative) are of interest for international practice as a starting material for accelerating selection work on productivity and stability in contrasting conditions of mountains and foothills.

Keywords: altitudinal zonation, highlands, foothills, photosynthesis, foliage, quality.

I. Introduction

Many agricultural experts rightly call amaranth one of the most promising plant resources (Kalac et al., 2000; Kuznetsov, 2012; Dinssa et al., 2019). A high-protein feed crop with a high productivity potential attracts the attention of many researchers (Noelting et al., 2019). Our research confirms the high productivity of green mass and seed production over the past 20 years (photo 1). With high productivity and productivity potential, the amaranth crop is able to generate a green mass yield of 100 tons or more per 1 ha.

Photo 1: High productivity of green mass and amaranth seeds (Kuznetsov I. Yu., 2008)

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In recent years, the ability of amaranth to adapt to any growing conditions has been established due to its high acclimatization and reduced soil toxicity (Bekuzarova et al., 2014). The use of amaranth becomes even more relevant due to its unique ability to adapt to different environmental conditions (Wegerle et al., 1995; Filatov et al., 2000).

A review of scientific publications only for the last year 2019 on issues related to the use of amaranth shows a sharply increased interest in this culture in different parts of the world in different areas of use. China (feed production) - in research by scientists (Li et al.,, 2019) noted the high efficiency of amaranth silage when mixed with soybean meal. There is an increase in the feed value and quality of the final product. Nigeria (aquaponics) - a high positive correlation was found between the dry biomass of amaranth shoots and the density of fish stocks. Analysis of amaranth cultivation in an experiment (Babatunde et al., 2019) showed that amaranth plants effectively use nitrogenous waste from aquariums to create their biomass. Brazil (plant protection) - spots on the leaves of the thin amaranth Amaranthus viridis caused by Cercospora brachiata are first reported in Brazil.

The identity of the etiological agent was confirmed by a combination of morphological and molecular information (Vieira et al., 2019). South Africa (vegetable growing) - the country has not escaped the scourge of malnutrition, poor health and even hunger, especially in rural areas. Calls to increase the consumption of local leafy vegetables are generally ignored and underused by modern agricultural systems. These vegetables are cheap and rich in nutrients and contain many healthy substances. Amaranthus hybridus L. it is one of these local leafy vegetables that has been rediscovered as a promising food crop mainly because of its excellent nutritional value of both seeds and leaves (Ngoroyemoto et al., 2019). Bangladesh (crop production) - studies have shown that the use of biohumus with legume crop rotations has the potential to significantly increase amaranth yields (Islam et al., 2019).

Mountain territories, located on all continents of the world and occupying significant areas on them, are the centers of the most important national, regional and international strategic interests.

In contrast to foothills and plains, mountain territories differ both in appearance and in tectonic structure, magmatism, and manifestations of various natural processes, where a significant amount and variety of resources and dynamic processes are accounted for per unit area (Abdurakhmanov et al., 2007). With changes in the altitude of the area above sea level, the entire complex of environmental factors changes: terrain, soil, air and soil temperature, moisture content and illumination, the duration of solar radiation during the day, there are significant changes in the physiological state of plants, affecting the morphology and their biochemical features (Budun, 1994).

The combination of a complex of the most important environmental factors that determine the vital activity of morphogenesis and plant productivity characteristic of high mountains cannot be reproduced in artificial controlled conditions. Therefore, testing different plant species in high-altitude conditions, primarily for agricultural purposes, is of great importance for their further selection for productivity, which is indicated by the ecological stability of plants, considered as a genetically determined ability to withstand abiotic and biotic stresses, and a number of other host-valuable traits (Bekuzarova et al., 2014).

A review of the research carried out on current areas of application of amaranth plants shows the need for research on different types of amaranth adapted to specific growing conditions. Research on amaranth plants in high-altitude zones of mountains and foothills is particularly relevant. In this regard, the purpose of our research (2017-2019) was to study the vegetation period, plant morphologies, the content of chlorophylls a and b, carotenoids, vitamins and carotene in amaranth plants of different species depending on the height above sea level. It was found that the altitude range of mountains and foothills has an impact on the duration of vegetation, quality indicators of amaranth plants of different species.

In accordance with this, the research was aimed at solving a number of problems, including: - the influence of the altitude zone on the course of the vegetation period of amaranth plants; - the morphology of amaranth plants of different species depending on the height above sea level; - the content of chlorophylls a and b, carotenoids in amaranth plants depending on the height above sea level;-the content of vitamins and carotene in amaranth plants depending on the height above sea level. The object of research is the amaranth plant of three species – forage (Amaranthus caudatus L.), grain (Amaranthus cruentus L.) and decorative (Amaran-thus hipochondriacus L.).

II. Materials and Methods

The study was conducted in 2017-2019 on the territory of the Republic of North Ossetia-Alania in two contrasting conditions: in the foothill zone (Mikhailovskoye village - 605 m above sea level) and in the mountains (Verkhny Fiagdon village - 1350 m above sea level) using three types of amaranth: forage (Amaranthus caudatus L.), grain (Amaranthus cruentus L.) and ornamental (Amaranthus hipochondriacus L.).

Sampling was carried out in mountain forest and meadow-steppe zones within 610-1400 m above sea level. The sum of daily average air temperatures above 10°C in these zones is 2200°C. Annual precipitation in the mountain-forest zone of broadleaf forests is 166–950 mm, and in the meadow-steppe belt it is from 520 to 750 mm, up to 890 in some years.

With an increase in altitude in the mountains every 100 m, the air temperature decreases by about 0.62 °C, hence the role of temperature as a limiting factor increases, solar radiation increases (the intensity of solar radiation increases by approximately 10% for each kilometer of altitude), and hence the degree of warming of the upper layers of the soil and the ground layer of the soil, increases the difference in daily temperatures, low pressure of carbon dioxide and water vapor (Sosnina et al., 2001; Khusnullin et al., 2008).

The greatest shortage of precipitation was observed in the summer months. The second half of the summer was characterized by a very high temperature and almost no precipitation. The first decade of May was characterized by the unstable behavior of the weather. The average daily air temperature reached 12.7°C. In the second decade of May, the unstable nature of the weather remained. The average air temperature was 11.30 °C. Precipitation was noted only at the end of the month, when the average daily air temperature was 13.50 °C. The monthly precipitation total amounted 75 mm. Such differences in temperature and the amount of precipitation did not significantly affect the productivity of amaranth culture.

The results of study showed that although the effect of climatic factors in different years varied, but on average the weather conditions for three years were favorable for the development of amaranth plants. Therefore, the results of the study are given below as three years average.

Figure 2: Amaranth plant nursery (Bekuzarova S. A., 2019)

The variants in the experiment were placed in a systematic way, by sequentially placing the plots in one tier. The experience is repeated four times. Plot length – 13 meters width – 1.6 m, the distance between 40 cm protective strip - 2 m Total area 1 option 20,8 m^2, 1 m^2 account. The experience area is 800 m^2. In the experiment, the following studies and observations were carried out using generally accepted methods: phenological and biochemical studies were conducted to identify changes in amaranth characteristics with change in altitudinal zonation. In our analysis we applied the most expressive plant characters: plant height, number of leaves, leaf surface area, mass of grains from one panicle, mass of 1000 grains, date of occurrence of phenophases, content of vitamins, carotene, chlorophyll as decisive indicators of ecological plasticity and survival of amaranth in extreme conditions of high mountains.

(Blankenship, 2002; Strzalka et al., 2003; Cai et al., 2003). The research was conducted in accordance with the guidelines of B. A. Dospekhov (1987), the state Commission for variety testing of agricultural crops

(1983), and the guidelines of the Russian academy of agricultural sciences (1997). Experimental data were analyzed using statistical methods (variance, regression, and correlation analyses) on a PC using STATISTICA 9.0 for Windows.

III. Results

The altitude gradient has a significant effect on the duration of the ripening period and the total length of the growing season. The main stress factors, increasing with altitude are a high diurnal temperature variation (from +7 to +35 ^{0}C) and windiness (Table 1).

Table 1: The effect of altitude zonation on the timing of vegetation period (2017-2019)

Plant species	Phenological phases					
	Sowing	Seedlings	Panicle panning	Phase of flowering	Milk Wax Phase	Full ripening phase
605 m above sea level						
Fodder amaranth (Amaranthus caudatus L.)	16.05	05.06	02.07	31.07	21.08	31.08
Cereal amaranth (Amaranthus cruentus L.)	16.05	06.06	01.07	31.07	19.08	02.09
Ornamental amaranth (Amaranthus hipochondriacus L.)	16.05	07.06	03.07	31.07	22.08	04.09
1350 m above sea level						
Fodder amaranth (Amaranthus caudatus L.)	15.05	30.05	23.06	26.07	12.08	24.08
Cereal amaranth (Amaranthus cruentus L.)	15.05	29.05	22.06	27.07	13.08	23.08
Ornamental amaranth (Amaranthus hipochondriacus L.)	15.05	31.05	24.06	28.07	14.08	27.08

Table 1 shows that the length of the growing season decreases with increasing altitude. On the plot of 605 m above sea level, the amaranth species went through a full development cycle, and the length of the growing season was 87-89 days depending on the species, and on the plot located at the altitude of 1350 m, the growing season was reduced by several days. Moreover, shoots in the mountain zone appeared 7 days earlier. This is due to the peculiarities of the light regime in the mountains, namely by the effect of increased solar radiation, despite the low temperatures at the beginning of the growing season. The duration of the germination-maturation period depended on the amount of precipitation ($r = 0.856$) and the GTC (hydrothermal coefficient) ($r = 0.905$). Precipitation increased the duration of the full growing season ($r = 0.871$).

The plant organism adapts to environmental conditions, and this affects the characteristics of the pigment apparatus. Structural elements of the assimilating cell involved in the absorption and conversion of the energy of sunlight may change. Various conditions of solar radiation cause changes in the number of leaves, their surface area, thickness, number of plastids, the size of chloroplasts, also they affect the height of plants (Mathur et al., 2015).

With changing environmental conditions, the growth rate and the size of the leaf surface change. The photosynthetic activity of the plant directly depends on the area of the leaf surface and the amount of chlorophyll in the leaves (Andreo et al., 1990).

Our results showed that with the rise in the mountains, some of morphological and biological indicators of the amaranth species under study change (Table 2).

Table 2: The morphology of plants in dependence on the altitude above sea level (2017-2019)

Plant species	Morphological and biological indicators (averaged)				
	Plant height, cm	Number of leaves, items.	Leaf area thousands of m^2/ha	Mass of grains in one panicle, g	Mass of 1000 grains, g
605 m above sea level					
Fodder amaranth (Amaranthus caudatus L.)	145	23	51,2	29,69	0,60
Cereal amaranth (Amaranthus cruentus L.)	129	22	85,7	29,83	0,57
Ornamental amaranth (Amaranthus hipochondriacus L.)	127	21	66,1	29,55	0,52
Smallest significant difference 05	1,6	0,7	9,4	0,09	0,02
1350 m above sea level					
Fodder amaranth (Amaranthus caudatus L.)	162	16	38,7	29,21	0,64
Cereal amaranth (Amaranthus cruentus L.)	167	15	51,2	29,54	0,43
Ornamental amaranth (Amaranthus hipochondriacus L.)	166	17	46,3	29,19	0,49
Smallest significant difference 05	2,1	0,6	6,7	0,01	0,04

Based on the table data, a natural difference in the increase in the leaf area and the height of amaranth plants with the ascent to the mountains was established, since amaranth belongs to the group of plants with C_4-type of photosynthesis, with a range of high temperatures up to + 35 °C, which provides a higher increase in biomass.

However, the the panicle mass and the mass of 1000 grains showed inverse dependence on altitude. This is due to the fact that the period for determining these indicators falls on the beginning of the end of August and the beginning of September, when the temperature difference between day and night (+32°C / +7°C) functions as a stress factor. Another abiotic factor is wind speed, which reaches in the studied mountain zone 7 m/s. Consequently, leaves sharply reduce stomatal conductance, the diffusion resistance of leaves occurs at high temperature, PAR and relatively low relative humidity, acting as a regulator of the water balance of amaranth plants. This significantly increases the water deficit, the amount of moisture in the leaves drops significantly, the water potential decreases, the osmotic pressure rises and the conductivity of the water necessary for the development of inflorescences decreases (Javadmanesh et al., 2015).

Amaranth plants in the mountains are exposed to powerful flux of ultraviolet rays, and they have a high ratio of chlorophyll *a* and *b*. At noon, when sunlight contains a maximum of short-wave high-intensity radiation, their content increases. Based on this, it seems very important to determine the number of chlorophylls a and b, carotenoids and vitamins, as one of the groups of active metabolites that are of particular importance in the life of the plant itself, as growth and development factors also actively involved in oxidation-reduction processes (Table 3).

Table 3: The content of chlorophylls *a* and *b* and carotenoids in dependence on the altitude above sea level (2017-2019)

lant species	Pigment content in plant material, mg/g of fresh mass		
	Chlorophyll *a*	Chlorophyll *b*	Carotenoids
605 m above sea level			
Fodder amaranth (Amaranthus caudatus L.)	1.4	0.4	0.5
Cereal amaranth (Amaranthus cruentus L.)	1.9	0.8	0.4
Ornamental amaranth (Amaranthus hipochondriacus L.)	1.6	1.0	0.5
Smallest significant difference 05	0,12	0,15	0,08
1350 m above sea level			
Fodder amaranth (Amaranthus caudatus L.)	2.1	0.7	0.6
Cereal amaranth (Amaranthus cruentus L.)	2.5	0.7	0.7
Ornamental amaranth (Amaranthus hipochondriacus L.)	2.3	1.3	0.6
Smallest significant difference 05	0,14	0,01	0,03

It was found that in the mountain zone of the North Ossetia-Alania, with an increase in the temperature of air and soil, under an excessive amount of solar radiation in all types of amaranth plants, the number of pigments of the photosynthetic apparatus increases by 1.5-2 times. Heat effect is reduced, and the risk of possible plant overheating decreases. The absorption maximum shifts to the short-wavelength direction, where light quanta at high energy have a lower thermal effect. Thus, the most of chlorophylls belong to the photo-absorbing complex of photosystem. The shift in the ratio of chlorophylls, apparently, is the result of genetic effect, i.e., adaptation to lighting conditions.

Thus, the pigment complex of plants is a complex and labile system that is sensitive to changes in environmental conditions.

Also, vitamins, being structural elements of plant enzymes, respond to changes in environmental conditions, in particular, altitude gradient. We found that the content of certain vitamins in amaranth plants increases with increasing altitude (Table 4).

Table 4: Vitamin and carotene content in dependance on altitude above sea level (2017-2019)

Plant species	Vitamin and carotene content, mg%				
	Vitamin A	Vitamin C	Riboflavin	Rutin, %	Carotene, mg/kg
605 m above sea level					
Fodder amaranth (Amaranthus caudatus L.)	21,2	387,5	1,27	1,7	53,7
Cereal amaranth (Amaranthus cruentus L.)	23,1	353,2	2,1	2,1	54,0
Ornamental amaranth (Amaranthus hipochondriacus L.)	17,3	367,2	1,45	1,6	53,2
1350 m above sea level					
Fodder amaranth (Amaranthus caudatus L.)	22,4	697,2	1,65	2,3	57,6
Cereal amaranth (Amaranthus cruentus L.)	26,7	693,0	2,98	2,7	59,3
Ornamental amaranth (Amaranthus hipochondriacus L.)	19,3	684,2	1,83	1,9	58,5

According to the table, the altitudinal gradient affects the accumulation and increase in the amount of vitamins and carotene. Apparently, in the mountains in amaranth plants, a protective mechanism is activated that protects vitamins from radiation destruction. This feature is practically valuable, and is significant in relation to the quality of the forage base of the highlands.

IV. Discussion

The use of amaranth in agricultural production is more relevant than ever before. The use of amaranth is increasingly finding support from both science and industry (Yao et al., 2019). At the same time, other uses of amaranth are being tested.

According to Barros R. I. et al. (2020) the edible flowers of Amaranthus hypochondriacus are gaining new interest as potential sources of biologically active compounds. Amaranth culture has demonstrated high antioxidant capacity for ORAC and FRAP analysis. Thus, this study showed the variety and abundance of natural antioxidants present in edible flowers that can be investigated for use in functional foods and pharmaceuticals. This study coincides with the results of our studies, which show a high content of vitamins and carotene, thereby confirming the high value of amaranth in the human diet.

The changes that occur in our experiments with amaranth plants of different species depending on the altitude above sea level are consistent with the results of research by Artemyeva E. P. et al. ((2019). Temperature and humidity had a great influence on amaranth plants. In years of low yields associated with high temperatures and arid-moderate humidity, the studied amaranth species realized the ability to rapidly develop and transition to seed production. At that time, when the temperature and excessive humidity decreased, the seed productivity of the crop decreased or was absent.

In favor of the high value of amaranth in human and animal nutrition, a study by Sarker U. et al. ((2019). A correlation study showed that all the antioxidant components of red amaranth have strong antioxidant activity. The present study showed that two of the genotype of red are a great source of antioxidants, which require a detailed pharmacological studies. These results add value to our research and are consistent with it.

According to the results of research in 2017-2019, we can conclude that the studied species of amaranth in the highlands of the Republic of North Ossetia-Alania showed a good adaptive potential under extreme loads of climatic factors. The experiments showed an increase in the content of chlorophylls *a* and *b*, carotenoids in the studied species of amaranth with an increase in altitude above sea level. The high-altitude gradient affects the accumulation and increase in the amount of vitamins and carotene in amaranth plants, which is of practical importance in relation to the quality of the food base of the highlands.

V. Conclusions

According to the results of research in 2017-2019, it can be concluded that the studied species of amaranth in the highlands of the Republic of North Ossetia Alania showed a good adaptive potential under extreme loads of climatic factors, in which a full cycle of development took place over a shorter growing season due to good leaf migration, taking into account C_4-type photosynthesis.

The length of the growing season for amaranth plants decreases as the altitude rises above sea level and the experimental site is located along the altitude gradient. On a plot of 605 m above sea level, the length of the vegetation period for amaranth plants is 87-89 days depending on the species, and on a plot located at an altitude of 1350 m, the vegetative period has been reduced by several days. At the same time, seedlings in the mountain zone appeared earlier by 7 days.

There is a natural difference between the increase in leaf area and the height of amaranth plants with the ascent to the mountains, but the indicators of the panicle grain mass and the mass of 1000 grains have an inverse relationship. It was found that in the mountain zone of the RSO - Alania with an increase in air and soil temperature, with an excess amount of solar radiation, the number of pigments of the photosynthetic apparatus increases by 1.5-2 times in all types of amaranth plants. The thermal effect is reduced, and the plant reduces the risk of possible overheating.

With an increase in altitude, the amount of solar radiation increases, which leads to an increase in the content of chlorophyls *a* and *b*, and carotenoids in the studied species of amaranth. The altitude gradient affects the accumulation and increase in the amount of vitamins and carotene in amaranth plants, which is of practical importance in relation to the quality of the forage base of the highlands.

The studied species of amaranth (grain, fodder, decorative) are of interest for international practice as a source material for accelerating selection work on productivity and stability in contrasting conditions of mountains and foothills.

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