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Variability of morphological characteristics of red forms of amaranth with a high content of biologically active substances under conditions of the Moscow region

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Abstract. The study of variability of morphological features in red-colored varieties of amaranth and their correlations at different stages in the conditions of the Moscow region makes it possible to identify features that affect productivity, amount of amaranthine and other biologically active substances. After analyzing vegetative characteristics, the varietal features of amaranth plants were proved to have a smaller impact on 'root length', 'plant height' and 'number of leaves' characteristics than the cultivation conditions, especially at the initial stages (ISB (Influence share of the weather conditions) from 22 to 58 %). It follows from the phenotypic variability analysis that the genotypic component values varied significantly only at the last stages (Cvg > 35 %). The maximum values of phenotypic variability were marked in all varieties at the stage of active growth considering the 'root length' (Cve = 32…47 %) and the 'number of leaves' (Cve = 48…85 %). The generative characteristics seemed to be significantly influenced by the varietal factor (ISA (Influence share of varietal characteristics) = 40…88 %) starting from the third stage. The genotypic component of all varieties was high considering the inflorescence weight (Cvg = 75…86 %). In signs of general productivity, it was studied that the leaves (93…112 g/plant) contributed the most for amaranth forms, which mass in all varieties largely depended on weather conditions (ISB > 55 %). The interrelation of the leaves productivity was noted high with all the vegetative characteristics on phase III–V (r = 0.71…0.92) and with 'inflorescence mass' on phase V–VI.

Keywords: *Amaranthus* L., morphology, phenotypic variability, productivity, amaranthine

Conflicts of interest. The authors declared no conflicts of interest.

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Introduction

Amaranthus L. plants are a source of valuable bioactive compounds that could be used in various spheres of national economy. Amaranth exceeds traditional grain and vegetable crops in nutrients content especially in protein and fat; the amaranth protein is especially valuable, as it contains the optimal ratio of essential amino acids [1, 2]. Leaves and inflorescences of red amaranth forms are raw materials for a valuable food dye — amaranthine, its antioxidant properties could be compared with ascorbic acid [3].

An important feature of the amaranth is plasticity, which ensures the variability both of plant morphological characteristics and of biochemical composition of substances and their content in leaves. The wide variability of the content of various amaranth substances is designed by its genotype and conditions of plant growth: region climate, cultural practices, stage of plant development [4, 5].

The aim of this study was to design the maximum plant productivity of red amaranth forms depending on the growth stage and establish the interrelation with the quantitative characteristics of amaranth plants grown in open field in Nonchernozem zone of the Russian Federation (Moscow region).

Materials and methods

Various morphological characteristics of red amaranth varieties (Valentina, Don Pedro and Fakel) and green amaranth varieties with red inflorescences (Pamyati Kovasa and Ecu 17020) were studied at biometric analysis depending on the growth stage and weather conditions in 2013—2016 [6–8].

The methodology for field experiments was developed considering the peculiarities of field experiment in selection, variety and primary seed breeding of vegetable crops set by OST-4671–78.

Field experiment in cultivation of varieties of different amaranth species was performed in open fields of Federal Scientific Vegetable Center in 2013—2016. Amaranth seeds were sown in open field in an ordinary way manually in the 4th decade of May. Field experiments (size of plots and sowing schemes) were carried out according to OST 4671–78. During the growing season we performed phenological observations, accounted for biometric characteristics, collected amaranth species. The phenological observations were carried out in accordance with the methodological guidelines for the study of green crops [9–12], the dates of onset of the most significant phases for amaranth plants were noted.

The obtained data were processed statistically using MS Excel spreadsheets. The necessary observations, accountings and analyzes were conducted on the techniques considering peculiarities of field experiment in breeding and crop production under the method of field experiment according to Litvinov [13].

For data processing, a scheme of two-factor experiment was used: influence of variety factor — Factor A (variety) and cultivation condition — Factor B (year) on variability of the studied characteristics. The total phenotypic dispersion is represented by decomposition into individual components: environmental variability (Cve, %) and the influence of varietal factor — a genotypic component (Cvg, %) [13].

Results and discussion

Root length. Analyzing variability of 'root length' parameter, an increase in values was observed as the amaranth plants develop. The most favorable conditions for root system development in most varieties (except Valentina) were formed in 2013, when the average root length of plants was significantly higher by the beginning of flowering. Don Pedro variety had some significant differences between the years (Cve = 25…47 %). The parameters for 2014 are characterized by a sharp transition from phase II to phase III with achieving plateau after phase III. In 2013—2014, parameters of 'root length' for Fakel are characterized by a sharp increase from phase I to phase III. In 2015—2016 the values almost immediately achieve plateau: after phase I in 2015 and after phase II in 2016 [14].

The following features can be distinguished in green varieties. Pamyati Kovasa demonstrates slow growth of root system at the initial stages of its development only under unfavorable 2015 conditions. Ecu 17020 variety had the least susceptibility to the changing weather conditions during its vegetative growth (Cve < 20 %) [9, 14].

The results of two-factor analysis demonstrated that the varietal factors (factor A) of the amaranth plant have a smaller impact on root system growth than cultivation conditions (factor B — the year), especially at the initial development stages (Fig. 1). The influence of factor A ranged from 1 to 30 %, and factor B — from 20 to 57 %.

This is also confirmed by low values of genotypic component of phenotypic variability of 'root length' characteristics (Cvg < 15 %). The maximum values of ecological variability for all variety characteristics were noted at the stage of active growth (Cve = 29…44 %).

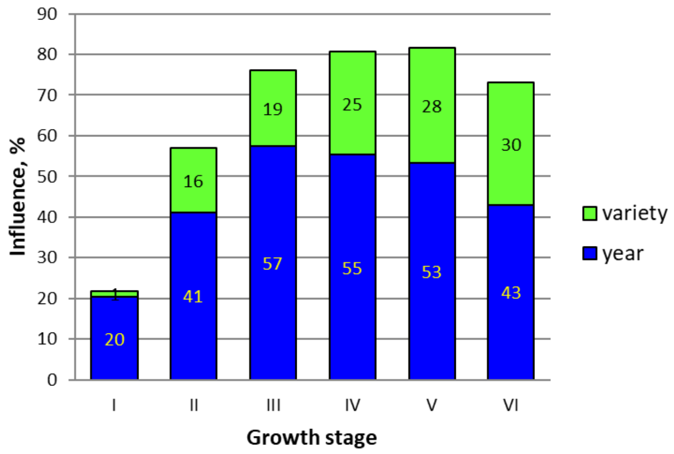

Fig. 1. Influence of genotype — factor A (variety) and cultivation conditions — factor B (year) on root length of amaranth varieties at different growth stages (2014—2016)

Height of plants. The highest growth parameters were marked in Ecu 17020 and Don Pedro, while Pamyati Kovasa amaranth had the lowest growth. The maximum height of plants was in 2013 (Fig. 2).

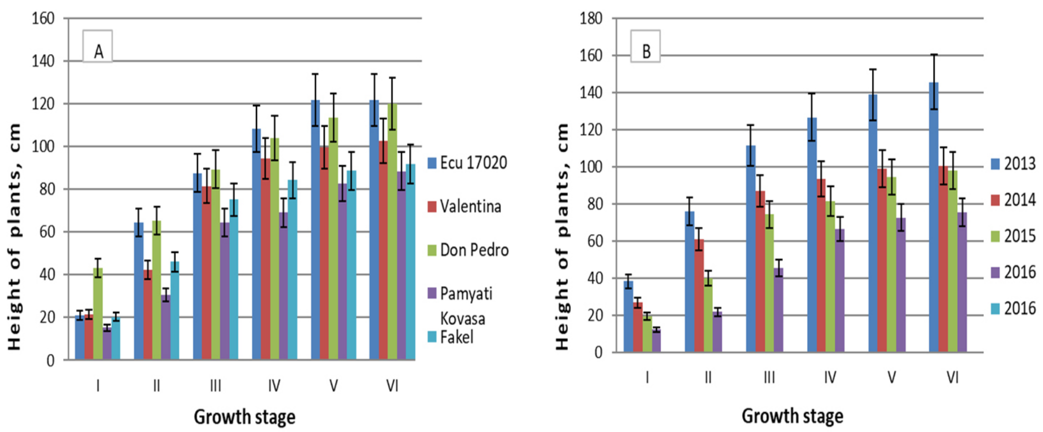

Fig. 2. Height of amaranth plants depending on variety (A), growth stage and research year (B)

Under the conditions of growing red variety Valentina, schedules for 2014—2015 reach a plateau at reproductive stages, and 2013 curve is constantly growing. Don Pedro's plant height curves have been observed to plateau at different stages of plant development. 2013 and 2014 can be considered for Fakel as reaching a plateau after phase III, and the indicators for 2015—2016 differ significantly at the early stages.

In 2013 and 2014, for green varieties Pamyati Kovasa and Ecu 17020, we can note a constant increase in ‘plant height’ curves. At the same time, in 2015—2016, graphs for Pamyati Kovasa reach plateau after phase III, and phase IV (See Fig. 2) [15, 16].

It should be noted that in different years the influence of year conditions was essential in phase II–VI $IS_B > 52$ %. The greatest varietal differences were noted at the last stages (Cvg > 35 %).

Number of leaves. The patterns above are similar to changing the ‘number of leaves’ characteristic. The influence of year conditions was significant (ISB > 34 %), and ‘plant height’ reached its maximum starting from phase III, ISB > 82 %. The differences between 2013 and 2015—2016 are the most noticeable. In 2014, there were no significant differences compared to 2013 in the active growth phase, but the number of leaves on plants was significantly lower at the beginning of budding and later stages [14, 15].

From the analysis of phenotypic variability, it follows that the values of genotypic component ranged throughout the ontogenesis (Cvg = 5…77 %). The values of environmental variability coefficients were the largest for Pamyati Kovasa variety (Cvg = 34 %); at other stages, the influence of year conditions was significant for all varieties (Cve = 52…87 %) depending on the variety and phase of development.

Plant productivity by total leaf weight. Some similar features in the development dynamics were identified for the ‘total leaf weight’ characteristic, however, the influence of weather conditions was significant at all stages of development, in contrast to the varietal factor (ISA < 15).

2013 was distinguished by high values at phase IV for Don Pedro, Fakel and Pamyati Kovasa varieties; at phase V — for Valentina variety. For Ecu 17020, the leaf mass after phase IV remained unchanged till the end of the growing season.

On average over the years, the highest productivity was noted in the three varieties — Don Pedro, Fakel and Pamyati Kovasa at the beginning of seed formation (95…112 g/plant). In varieties Valentina and Eku 17020 (more than 120 g/plant) — at the ripening stage (V phase). Varietal differences are more significant than ‘leaf mass’ and ‘number of leaves’ [13, 15, 16].

Inflorescence length. Among the studied varieties, two groups can be distinguished: with large inflorescences (Fakel, Valentina, Pamyati Kovasa) and small inflorescences (Don Pedro and Ecu 17020). Comparing the values for different years, general patterns were found: a high growth rate of inflorescences at the stage ‘beginning of budding-flowering’ and its slowdown to phase IV (Fig. 3). The most optimal conditions for Valentina and Don Pedro were in 2015; for Fakel and Ecu 17020 — in 2013 [17, 18].

Significant fluctuations in the coefficient of phenotypic variability were observed in late-ripening varieties of amaranth Don Pedro (Cve = 36…87 %) and Eku 17020 (Cve = 25…84 %) with maximum values in phases IV and V (Cve = 72…94 %). The values of genotypic component had the maximum variation a in phase IV (Cvg = 43 %).

These features explain the more significant influence of genotype on development of reproductive system of amaranth plants. The share of influence of this factor at the stages of maturation was more than 45 %, which is significantly higher than that of plant height (ISA < 25 %), root length (ISA < 30 %), and number of leaves, (ISA ≤ 5 %). At the same time, the effect of cultivation conditions, factor B, is significantly less (IBS < 37) (Fig. 3).

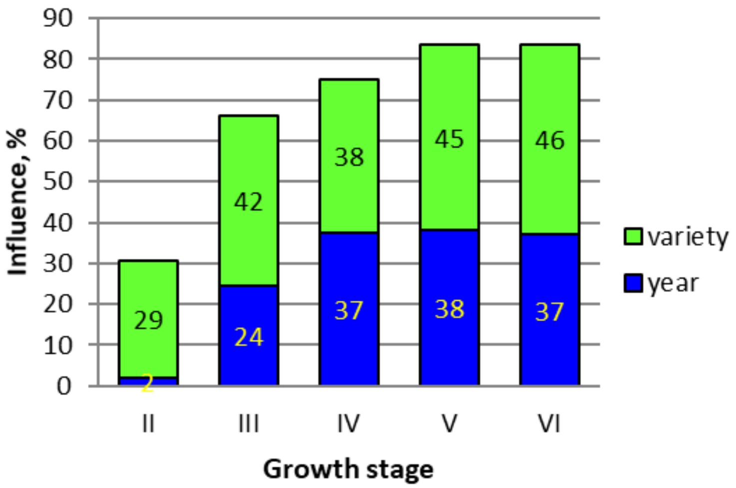

Fig. 3. Influence of genotype — factor A (variety) and cultivation conditions — factor B (year) on inflorescence length of amaranth varieties at different growth stages (2014–2016)

Inflorescence mass. On this basis, two groups of varieties can be distinguished: Valentina, Fakel and Pamyati Kovasa with large inflorescences (> 25 g); Don Pedro and Ecu 17020 with small inflorescences (< 10 g). Varietal differences were observed at all stages of inflorescence development (ISA = 43…87 %), and influence of year was more significant at budding stage (ISA = 37 %). The genotypic component of variability for inflorescence mass in all varieties was distinguished by high values of the studied trait in phases II–VI (Cvg = 75…86 %).

In the first group, Fakel and Pamyati Kovasa have a similar dynamics of inflorescence mass growth in all years, while in 2016 Valentina showed a sharp decrease in this indicator. In the second variety group, Eku 17020 was the most susceptible to changes in weather conditions and had a comparable mass of inflorescences in 2013 and 2014 [16, 19].

Analyzing the correlation of the total leaf productivity, it should be noted that it should be noted that in all studied varieties, high positive correlations were noted for ‘root length’, ‘plant height’ and ‘number of leaves’ in phases III and IV and for ‘number of leaves’ and ‘plant height’ in phases II and V (r > 0.84). The ratio of ‘leaf mass’ with generative characteristics is as follows: for ‘inflorescence length’ it is positive at stages II and V, for ‘inflorescence mass’, an increase in correlation with the last phase of inflorescence development can be noted (r = 0.8).

At the same time, significant relationships between the mass of inflorescence and other morphological characteristics of plants (root length, plant height, number of leaves) were not found in the studied varieties [8, 20].

Conclusions

Grouping varieties according to the total productivity of vegetative mass (leaves + inflorescence) depends on the phase of development — Pamyati Kovasa and Eku 17020 had the largest plant mass (> 100 g/plant) at the flowering stage, at the stage of seed formation this indicator was comparable in all varieties (115…121 g/plant), and at the stage of beginning of seed formation, Valentina could be distinguished by this parameter (more than 140 g/plant).

The greatest differences between the studied varieties in the group were noted for ‘plant height’ (Cvg > 25 %), the coefficient of genetic variability for number and weight of leaves was 15…27 % depending on the growth stage; for length of root and inflorescence Cvg < 15 %. Eku 17020 variety differs in plant height, Don Pedro — in number of leaves, Valentina and Eku 17020 — in leaf mass, Pamyati Kovasa — in inflorescence length, Fakel — in inflorescence mass.

Thus, the overall productivity (leaves and inflorescences) in the open ground of the Moscow region is due to early maturity, varietal characteristics of the reaction rate to changing weather conditions in the region, year of cultivation and the ratio between the main quantitative traits at different growth stages of amaranth plants.

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Изменчивость морфометрических показателей красноокрашенных сортов амаранта с высоким содержанием биологически активных веществ в условиях открытого грунта Московской области

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Аннотация. Изучение изменчивости морфологических признаков красноокрашенных сортов амаранта и их корреляционных взаимосвязей на разных стадиях онтогенеза в условиях Московской области позволило определить особенности, влияющие на формирование продуктивности, получение максимального количества амарантина и других биологически активных веществ. Анализ вегетативных признаков выявил, что сортовые особенности растений амаранта оказывают меньшее влияние на длину корня, высоту растений и число листьев, чем условия выращивания, особенно на начальных стадиях ($ДВ_в$ от 22 до 58 %). Исследование фенотипической изменчивости показало, что значения генотипической составляющей изменчивости варьировали на последних стадиях созревания (Cvg > 35 %). На начальных стадиях высокой изменчивостью отличились вегетативные признаки: длина корня (Cve = 32…47 %) и число листьев (Cve = 48…85 %) — в зависимости от условий года. В репродуктивный период развития у всех генеративных признаков фактор сорта был наиболее существенным начиная со стадии цветения (ДВА = 40…88 %). Значения признака — массы соцветий — варьировали в зависимости от влияния генотипической составляющей изменчивости всех сортов (Cvg = 75…86 %). Из анализа признаков общей продуктивности растений следует, что основной вклад у сортов амаранта вносят листья (93…112 г/растение), масса которых зависит от погодных условий ($ДВ_В$ > 55 %). Высокими корреляциями были отмечены взаимосвязи общей продуктивности листьев со всеми вегетативными признаками на III–V фазе (r = 0,71…0,92) и массой соцветия на V–VI фазах созревания.

Ключевые слова: *Amaranthus* L., морфология, фенотипическая изменчивость, продуктивность, амарантин

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