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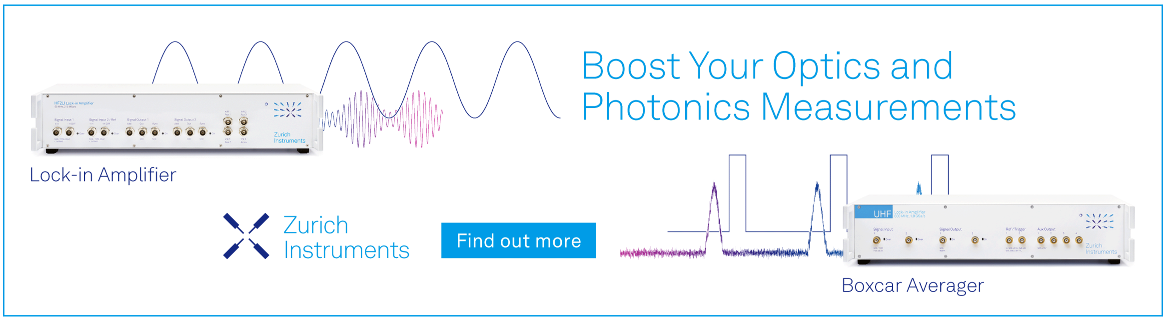

Morphometric Characteristics of *Amaranthus caudatus* L. in Temperate Continental Climate

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Abstract. The new climate conditions of introduced plants are often very different from their original native places of growing. In this case, these conditions can be considered as stressful. Plants under adverse environmental conditions can adapt at the morphological, physiological, and biochemical levels. This paper discusses the morphological traits of *Amaranthus caudatus* L. *cv. Edulis* during introduction process in temperate continental climate. The results show that a combination of environmental factors (temperature, soil moisture, day length) affects the growth and development of plants. Amaranth has a wide response norm and adapts well to new conditions. The functional dependency between a lamina's area and a petiole's length is obtained.

INTRODUCTION

Amaranths are very interesting candidates for an introduction procedure as multipurpose plants. The seeds and vegetative mass of these annual plants contain a large amount of protein, balanced in amino acid composition [1]. Some species of amaranths can be utilized as grains, while others can be used as vegetables. There are several geographical centers of amaranths cultivation: Central and South America, Southeast Asia and Africa. In Russia, interest in the cultivation of amaranths arose at the end of the last century.

In the Middle Urals, amaranths have been grown and extensively studied in the Botanical garden of the Ural Federal University for the past 30 years. The climate conditions of the Middle Urals differ from the tropical and subtropical climate of traditional places where amaranths grow. The amaranth species are known to be tolerant to adverse environmental conditions, including drought, poor or saline soils and high plant density, which was shown in the previously published works [2–4]. This tolerance has been associated with amaranths C_4 photosynthesis, high water use efficiency, the ability to develop long taproots and an extensive web of lateral roots. Some amaranth species are sensitive to the length of the daylight, which shows that they are short day plants [5, 6].

Adverse conditions in our region include a relatively short growing season (86–96 days) [7], frosts on the soil in early summer and early autumn. Furthermore, summer soil drought and waterlogging are possible during growing season. Daylight hours in the middle Urals vary from 17 to 12 hours from June to September. These conditions correspond to a long day growing. Environmental conditions determine the morphometric type of plants.

EXPERIMENTAL PART

The work was carried out in the Botanical garden of the Ural Federal University, which is located in the Middle Ural, Russia (56°50′N and 60°36′E, 255 m above sea level). Natural conditions correspond to the continental climate of temperate latitudes. The phase of active vegetation with temperatures above 10°C lasts about 130 days, while temperatures above 15°C (meteorological summer) last on average for 77 days (long-term averaged data). The soil in

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the experimental area was classified as sod-podzolic. For estimating weather conditions *HTC* (Selyaninov′s Hydrothermal Coefficient) was calculated (1):

$$HTC = \frac{\sum r}{\sum t} \times 10, \quad (1)$$

where $\sum r$ – total precipitation (mm), $\sum t$ – the sum of average daily air temperatures greater than 10 °C.

The Botanical garden has a large collection of seeds of amaranth species, varieties and cultivars. Seeds of *Amaranthus caudatus* L. *cv. Edulis* for our investigations were obtained from Ecological-Botanical Garden of the University of Bayreuth (Germany) through an international seed exchange. Seeds were sown on the first day of June 2019 to avoid damage to seedlings by frost on the soil. The spacing was set to 0.5 m between rows and to 0.20–0.25 m between plants. Plants were grown on small land plots with an average area of 4–5 m^2. After the emergence of seedlings, thinning and weeding were performed manually when necessary. Between the 10–14th of September 2019 thirty amaranth plants were randomly selected and examined.

After harvest the following quantitative characteristics were measured for each plant: stem height and number of leaves. The following morphometric traits for each metamer were measured: internode length and diameter, lamina width and length, petiole length, and inflorescence length. An area of a lamina was determined in cm^2 by the digital image of leaves using the software ImageJ.

For studying of the above-ground biomass structure plants were divided into stem, leaves and inflorescence. The wet and dry weight of stems, leaves and inflorescences were determined on laboratory scales. To determine dry weight parts of plants were kept in a drying chamber at 80°C until a constant weight was obtained. The water content was calculated based on the ratio between the difference of the wet and dry weight and the wet weight. The following morphometric indicators were calculated: *SMR* (Stem Mass Ratio, the proportion of dry weight of stem in the dry weight of whole plant), *LMR* (Leaf Mass Ratio, the proportion of dry weight of leaves in the dry weight of whole plant), *GMR* (Generative Mass Ratio, the proportion of dry weight of inflorescence in the dry weight of whole plant), *LAR* (Leaf Area Ratio, ratio of leaf area to the dry weight of whole plant). The measurements were statistically processed.

RESULTS AND DISCUSSION

Long-term phenological observations in the Middle Ural [7] have shown that the main limiting factors in the development of amaranths were low summer temperatures, excessive moisture and a short meteorological summer. The *HTC* characterizes the ratio of moisture and heat and has an optimal value for several kinds of crops cultivated. In the growing season of 2019, with the total precipitation of 266 mm and the total active temperatures of 1569°C, the *HTC* was equal to 1.7. This summer was not very good for the growth and development of amaranth. Usually, ripe amaranth seeds are formed in hot dry years with *HTC* value of less than 1. These conditions are considered optimal for amaranth growth and seed production. In vegetation periods with *HTC* value above 1, due to excessive moisture and a low amount of active temperatures, the beginnings of budding and florescence occurred at a later time and the seeds did not mature. The vegetative stage of *A. caudatus cv. Edulis* was the longest in the ontogenesis and lasted 45 days. As a result, most of the plants started inflorescence on the 26th of August.

During introduction process the height of studied amaranth species varied from 162 to 191 cm with an average of 174 cm. The coefficient of variation for this trait was 4.6%. The average stem diameter was measured to be 1.5 cm near the plant’s base.

The lamina shape of *A. caudatus cv. Edulis* is oblong with a solid serrated edge. The leaves are arranged alternately along the stem, which makes it possible to maximize their illumination. The number of leaves on the plant varied from 21 to 33. Average number of leaves per plant was 27 and the total average lamina surface was 1969 cm^2. The degree of foliage of the plant serves as a morphometric response to the intensity of radiation and the length of the daylight. The average lamina area was 73 cm^2, with a length of 13.1 cm and a width of 7.7 cm. The leaves with the biggest area of a lamina were located, on average, in 12–14 internodes counting from the ground with an average value of 120 cm^2 (Fig. 1).

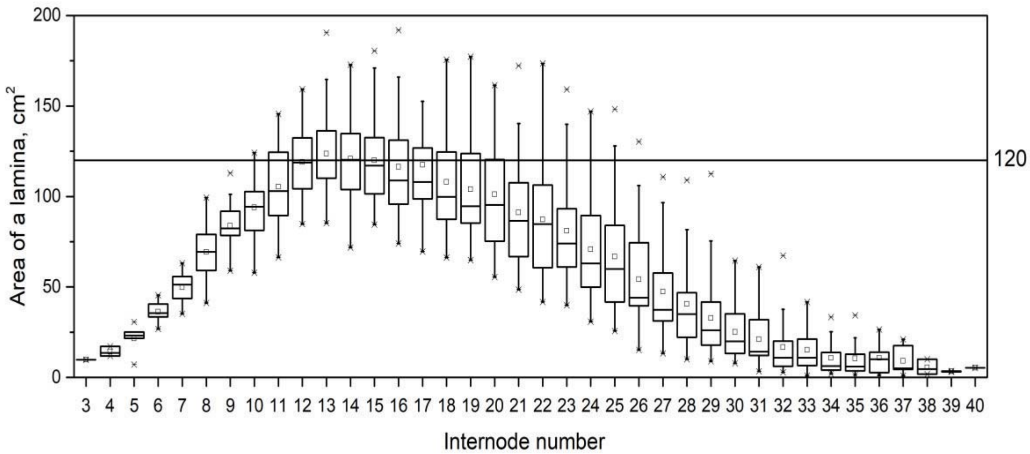


FIGURE 1. Box chart distribution of area of a lamina dependence on the internode number for a set of thirty plants of *Amaranthus caudatus* L. *cv. Edulis*

Morphometric traits of other amaranth species and hybrids were studied by other authors and showed heterosis effect in some traits, like the length and the width of leaves and the length of stems [6].

In addition to the leaves, an important organ of amaranth plants is inflorescence. Flowers of *A. caudatus cv. Edulis* collected in light-green and spreading complex inflorescence consisting of individual branches (Fig. 2).

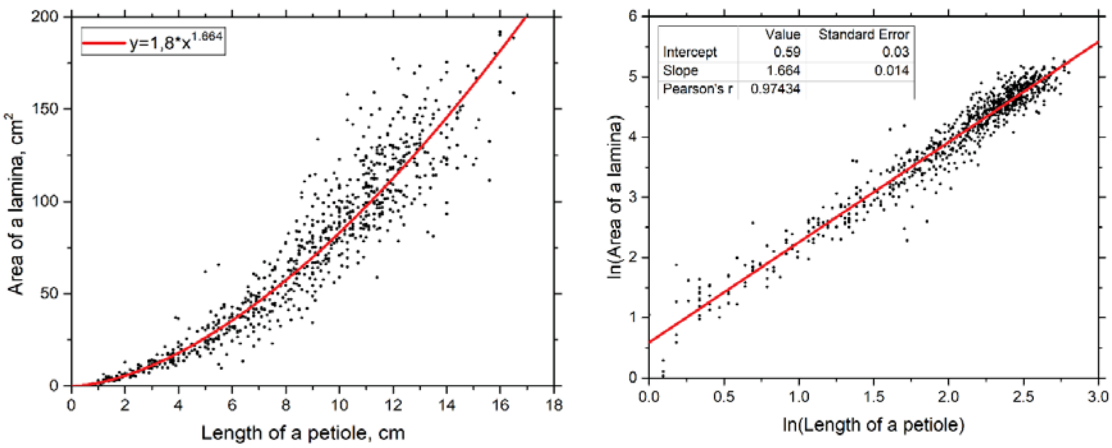
FIGURE 2. Inflorescence of *Amaranthus caudatus* L. *cv. Edulis*

Under stress conditions (i.e. drought or low temperature), plants form such an inflorescence, that it is able to provide seeds with all necessary metabolites until they fully mature. In the growing season of 2019, the studied cultivar had an average inflorescence length of 18.0 cm, with an average length of individual branch equal to 5.7 cm. This species did not form ripe seeds in 2019 because this growing season was adverse for the growth and development of amaranth, as it was mentioned above.

The results of our research show that at the end of the growing season the wet weight of the above-ground plant varied from 177.9 to 597.2 g, the dry weight varied from 25.5 to 88.2 g. The average water content in plant was 85.4 ± 0.7%. Most of the water was stored in the stems (70 ± 2% of the total water content), compared to the leaves (16 ± 1%) and inflorescence (14 ± 3%). The distribution of the dry weight of individual plant organs is important to the introduction process research. In the studied amaranth, the proportion of stem *SMR* was 63 ± 1%, leaves *LMR* was 20 ± 2% and inflorescence *GMR* was 17 ± 3%. The index *LAR* was approximately 50 cm^2 g^{-1}. A high value of *LAR* is typical for plants with a stress-tolerant ecological strategy. A positive correlation was found between dry vegetative above-ground weight and leaf area ($r = 0.96$ at significance level $p \leq 0.05$).

The functional dependence of a lamina's area (S) on a petiole's length (L) was obtained (2) through a log-log analysis (Fig. 3) of the big collection of amaranth leaves:

$$S = (1.8 \pm 0.1) \times L^{1.664 \pm 0.014} \quad (2)$$



(a) (b)

FIGURE 3. A lamina's area on a petiole's length dependence for leaves of *Amaranthus caudatus* L. *cv. Edulis:* (a) – the functional dependence, (b) – the log-log analysis

CONCLUSION

Amaranths adapt well to the new environmental conditions due to a wide response rate and genetic polymorphism [2, 5, 6]. Adaptation occurs at morphological, physiological and biochemical levels. The study of morphological characteristics of *A. caudatus* L. *cv. Edulis* in the temperate climate conditions shows that, plants can grow to the average height of 174 cm with the average wet weight of the above-ground plant equal to 299 g and the average dry weight equal to 43 g. The total average lamina surface per plant was determined to be 1969 cm^2, with the biggest contribution corresponding to the leaves attached to the internodes from 12 to 14. Several morphometric indicators were calculated for plants of *A. caudatus* L. *cv. Edulis*, including *SMR*, *LMR*, *GMR* and *LAR*. The study also shows that lamina's area depends non-linearly on a petiole's length, with the exact formula obtained through statistical methods.

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REFERENCES

1. R. M. Saunders and R. Becker, Advances in Cereal Science and Technology **6**, 357–403 (1984).
2. A. Ahrar, F. Paknejad, S. A. Tabatabaei, F. Aghayari, and E. Soltani, Italian Journal of Agrometeorology **3**, 31–40 (2020).
3. V. M. Caselato-Sousa and J. Amaya-Farfán, Journal of Food Science **77(4)**, R93–R104 (2012).
4. V. V. Valdayskikh, P. Yu. Voronin, E. P. Artemyeva, and V. P. Rymar, AIP Conference Proceedings **2063**, 030023 (2019).
5. R. Andini, M. I. Sulaiman, R. Moulana, K. P. W. Hmon, and R. Ohsawa, IOP Conference Series: Earth and Environmental Science **425**, 012005 (2020).
6. V. Lanta, P. Havránek, and V. Ondřej, Plant, Soil and Environment **49**, 364–369 (2003).
7. E. P. Artemyeva, V. V. Valdayskikh, T. A. Radchenko, and P. A. Belyaeva, AIP Conference Proceedings **2063**, 030002 (2019).