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Yielding capacity of amaranth grain (*Amaranthus hypochondriacus*) depending on fertilizers

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ABSTRACT

The research was conducted on the research field of Lviv National Agrarian University on dark gray podzolic light loamy soil. Hydrothermal conditions differed from the average of many years data by more precipitation. In 2019, during the growing season it fell by 53 mm above the rate, in 2020 - by 129 mm, in 2021 - by 73 mm. The aim of the research to define the amaranth nutrition system in conditions of sufficient and excessive moisture, seven rates of mineral fertilizer application were studied: $N_0P_0K_0$, $N_{40}P_{20}K_{40}$, $N_{80}P_{40}K_{80}$, $N_{120}P_{40}K_{80}$, $N_{160}P_{80}K_{120}$, $N_{200}P_{80}K_{120}$, $N_{200}P_{80}K_{160}$. Under the influence of fertilizers, plant height increased from 147.1 cm to 208.2 cm, panicle length - from 32.2 cm to 71.7 cm, seed weight from one plant - from 12.9 g to 27.8 g, weight of 1000 grains - 0.86 g to 0.91 g. The number of plants before harvest was in the range of 18-20 plants/m^2. Increasing of the application rate of mineral fertilizers from $N_0P_0K_0$ to $N_{200}P_{80}K_{160}$ provides the increase of the yielding capacity of amaranth grain of the variety Kharkiv 1 from 2.31 t/ha to 4.88 t/ha, or by 2.57 t/ha. Yield depended mostly on nitrogen fertilizers, application of N_{40} on variants with the rate of $N_{120}P_{40}K_{80}$ and $N_{200}P_{80}K_{120}$ fertilizers resulted in a further increase of the yield by 0.41 t/ha and 0.34 t/ha. Increasing the potassium rate by K_{40} on variant $N_{200}P_{80}K_{160}$ did not provide a significant (0.04 t/ha) increase of the yield. The highest level of yielding capacity is formed by the following structural elements: grain weight from one plant - 27.8 g and number of plants - 18 p/m^2.

Keywords: pseudograins, fertilizer rates, structure, productivity

INTRODUCTION

Amaranthus is an ancient crop, the potential of which has not yet been realized. Since 1970, amaranth has been gradually restored as a cultivated plant. After almost 400 years of oblivion, it is now grown in many countries around the world. The largest producers of amaranth grain are Mexico, Russia, China, India, Nepal, Argentina, Peru and Kenya (Petrychenko and Lykhochvor, 2021). However, data of the world production of amaranth grain are scarce, and FAOSTAT does not publish any information of its production. In Ukraine, amaranth spread in 1989-1992 (Zadorozhna, 2011).

Amaranth is suitable for making flour, popcorn, bread and many other healthy foods that prevent various diseases. Therefore, amaranth is perspective for the pharmaceutical industry and the production of many functional foods.

It is able to increase immunity, protect against radiation (Saratovsky and Saratovsky, 2014). The unique substance squalene, which contains up to 8% in oil, has been isolated from amaranth (Fedorchuk et al., 2017).

Amaranth is an effective bioaccumulator of heavy metals. It has energy value at the level of straw cereals (Ulicny et al., 2013).

In the world mainly three species of amaranth are cultivated as cereals All bioactive compounds *Amaranthus hypochondriacus* have a strong antioxidant effect. Amaranth is a source of betalaine (Sarker and Oba, 2020). The potential of many species of amaranth seems huge and promising, which makes its study for health and industrial use is extremely necessary (Aderibigbe et al., 2020). Due to the growing needs of the world's population for food, health and well-being, as well as to provide food for those who do not eat, amaranth is probably the best choice of all cereals and pseudograins (Asel et al., 2020).

Pseudograin crops are becoming a current trend in the human diet as gluten-free (GF) grains with excellent nutritional and food value. Pseudograins are a good source of starch, fiber, protein, minerals, vitamins and phytochemicals such as saponins, polyphenols, phytosterols, phytosteroids and betalains, which have potential health benefits (Martínez-Villaluenga et al., 2020).

In Ukraine, two species of amaranth were studied - paniculate and caudate, which are the most valuable in many respects (Zadorozhna, 2011, Demidas and Sliusar, 2019). Among cultivated amaranths, *Amaranthus caudatus*, *Amaranthus cruentus* and *Amaranthus hypochondriacus* have the highest nutritional value (Skwarylo-Bednarz et al., 2020).

The maximum yielding capacity of amaranth causes increased requirements for the provision of mineral nutrients. In terms of nutrient requirements, amaranth is even superior to corn, which is also a tropical crop (Saratovsky L and Saratovsky A, 2014).

Data as to the yield potential of this crop are very different. The yielding capacity of Amaranth grain is 1.5-2.0 t/ha, but it can reach 6 t/ha (Demidas and Sliusar, 2019). Similar data of yield potential are presented in another source: yielding capacity of grain without fertilizers is 20 - 30 kg/ha, with fertilizers is 30-40 kg/ha, with irrigation - 50 kg/ha (Duda, 2017). Lack of high-yielding technologies, non-compliance with cultivation techniques do not allow to fully realize the potential of this crop.

One of the main reasons for the incomplete realization of the genetic potential of amaranth yielding capacity is the insufficient study of the features of its fertilizer system for specific soil and climatic conditions. In most researches, amaranth has responded to increased mineral fertilization rates with a significant increase in yield (Makinde et al., 2011). To form the yield at the level of 10 t/ha of dry matter, it endures $N_{150-175}P_{90-100}K_{450-550}Ca_{210-250}Mg_{80-100}$ (Rakhmetov and Rybalko, 2005).

There are very different recommendations as to the rates of application of mineral fertilizers and the expediency of certain nutrients application. Thus, according to (Savchuk et al., 2016) it is recommended to apply fertilizers in a ratio of 1:1:1 in the amount of $N_{60}P_{60}K_{60}$. In the work of Zadorozhnaya I.S. (Zadorozhna, 2011) it indicates that the highest yielding capacity was obtained applying complete mineral fertilizer in the rate of $N_{90}P_{90}K_{90}$. Taking into account the removal of nutrients , a different ratio of trace elements is indicated: N: P: K = 1,0:0.8:3.0 (Duda, 2017). In some researches the rate of fertilizer is not concretized, but it is indicated that it is advisable to make a calculated rate of fertilizers for the planned yielding capacity of amaranth grain (Voitashenko, 2005 a; b).

Amaranth intensively uses nutrients, so the main treatment is made of phosphorus and potassium fertilizers ($P_{60-100}K_{90-120}$), and in spring - nitrogen ($N_{140-200}$). Under cultivation 2/3 of the total nitrogen is applied, in fertilization - 1/3 (Petrichenko and Likhochvor, 2021). The results of research show that nitrogen-phosphorus fertilizers were the most effective as to the increase of amaranth seed productivity, and the application of their increased rates ($N_{90}P_{90}$ against K_{30}) allowed to obtain the highest (1.47 t/ha) seed yielding capacity (Krasnenkov et al., 2004).

It is recommended to apply mineral fertilizers under amaranth in the rate of $P_{45-60}K_{45-60}$ (Demidas and Sliusar, 2019). However, there is conflicting evidence that phosphorus and potassium fertilizers did not increase yields. They had a significant effect only when co-applied with nitrogen, and nitrogen fertilizers significantly affected yields (Akamine et al., 2020).

In the soil and climatic conditions of the northern steppe of Ukraine, the yield increase of amaranth grain (Amaranthus paniculatus) from the application of complete mineral fertilizer ($N_{90}R_{90}K_{30}$) was low and formed only 0.42 t/ha, compared to control without fertilizers (Dudka, 2019). It is recommended to apply mineral fertilizers in the rate of $N_{120}P_{70}K_{70}$ (Bielski and Szwejkowska, 2015).

In the research of two levels study of fertilization by macroelements (1 - $N_{90}P_{26}K_{50}$; 2 - $N_{130}P_{30}K_{58}$), both varieties of amaranth responded significantly to increasing rates of fertilizers. A particularly large increase of the yield of aboveground biomass was obtained at a higher level of NPK application (Skwaryło-Bednarz et al., 2014).

Nitrogen application rate should be N_{110} (Pospišil, 2006). The one-time main application of nitrogen N_{100} to soil is also recommended (Olofintoye et al., 2015). The greatest efficiency during the cultivation of amaranth is obtained with the application of ammonium nitrate and urea (Breus, 1992). In some experimental researches the increased yields provided the application of vermicompost with the rate of 5 t/ha (Tayade, 2012). There is evidence that higher nitrogen supply leads to increased respiratory conductivity and transpiration (Cechin and Valquilha, 2019).

Batch application of nitrogen fertilizers proved to be effective. Thus, the best plant development, flowering and highest yielding capacity were when nitrogen was applied twice: N_{60} in the early stages of growth and N_{30} at the beginning of flowering (Śmigerska, 2016). According to data (Makinde et al., 2011), where three variants of nitrogen application were studied, the following results were obtained: in the variant with N_{60} application before sowing, the yielding capacity was 1.52 t/ha; with the application of N_{60} before sowing plus N_{30} at the stage of shoot formation, it increased to 1.93 t/ha; with three applications of nitrogen according to the scheme of N_{60} before sowing plus N_{30} in the phase of shoot formation plus N_{30} in the inflorescence phase the yielding capacity was the highest – 2,03 t/ha.

The application of urea together with organic and bacterial fertilizers provided an increase of the yield to 1,751 t/ha, while in the control without fertilizers it was only 1,151 t/ha (Parmar and Patel, 2008).

With the application of a high rate of nitrogen fertilizers N_{200} yielding capacity increased by only 35%, which is probably due to other limiting factors that did not increase the efficiency of nitrogen fertilizers (Tabrizi et al., 2013).

Due to the large variety of data, often contradictory, it is important to study the rates of mineral fertilizers during the cultivation of amaranth in conditions of sufficient moisture.

MATERIALS AND METHODS

Field research was conducted on the research field of the Department of Plant Technology of Lviv National Agrarian University. Soil - dark gray podzolic light loamy, with the following agrochemical parameters. Turin humus content 2,19%, pH of the salt extract KCl - 6,07. Lightly hydrolyzed nitrogen (N) according to Cornfield 108 mg/kg soil, mobile forms of phosphorus (P_2O_5) according to Chirikov 126 mg/kg of soil, mobile forms of potassium (K_2O) according to Chirikov 111 mg/kg of soil. Copper content (Cu) 1,24 mg/kg; Zinc content (Zn) 1,08 mg/kg; manganese content (Mn) 17,0 mg/kg; boron content (B) 0,92 mg/kg; iron content (Fe) 132,0 mg/kg.

Hydrothermal conditions in the years of researches differed slightly from the average long-term data. In particular, in 2019 and 2020, the average temperature during the growing season was higher by 1.3 °C and 0.5 °C, and was 16.1 °C and 15.3 °C, respectively. In 2021, the temperature regime corresponded to the average long-term data, the average temperature was 14.8 °C. During the growing season, in all years of the research, more precipitation fell compared to the long-term average: in 2019 by 53 mm, in 2020 by 129 mm, in 2021 by 73 mm.

The field experiment was performed four times repetitions. The total area of the experimental plot was 30 m^2, registered one 20 m^2. The predecessor of amaranth in the years of research was winter wheat. Tillage in the fall was carried out according to the type of improved. In the spring, at the first opportunity to enter the field, the moisture was closed with the next 2 cultivations. Pre-sowing tillage was carried out to a depth of seed wrapping, 1-2 cm, using a combined tool "Compactor". Mineral fertilizers were applied according to the research scheme: $N_0P_0K_0$, $N_{40}P_{20}K_{40}$, $N_{80}P_{40}K_{80}$, $N_{120}P_{40}K_{80}$, $N_{160}P_{80}K_{120}$, $N_{200}P_{80}K_{120}$, $N_{200}P_{80}K_{160}$. Phosphorus (Superphosphate, P_{20}) and potassium (Potassium chloride, K_{60}) fertilizers were applied in the fall for plowing. Nitrogen fertilizers were applied in the spring for pre-sowing tillage. The variety Kharkiv 1 was sown by a wide-row method with 45 cm row spacing, on April 25, the sowing rate was 0.8 kg/ha. Horsch Pronto 4 DS drill was used. Inter-row tillage and the herbicide Fusilade Forte (1.0 l/ha) were used to control weeds. Amaranth harvesting was carried out in two stages: mowing - in the phase of full ripeness of seeds in the lower and middle parts of the panicle, after drying amaranth pancakes were threshed.

Statistical data processing was performed by dispersive analysis (ANOVA) using the program "Statistica 6.0". Data were compared using the Tukey test. Differences between samples were considered statistically significant at $P<0.05$. The data in the tables are presented as the arithmetic mean with standard deviation (x ± SD).

RESULTS AND DISCUSSION

The yielding capacity of amaranth grain depends on many elements of the structure. Tall plants were formed in all variants, which is explained by the sufficient supply of moisture during the years of research. In the variants with higher fertilizer rates, the plants were higher, with the application of $N_{200}P_{80}K_{160}$, the height of the plants prevailed the control ($N_0P_0K_0$) by 61.1 cm (Table 1).

Fertilizers did not only affected the growth processes, but also caused positive changes between the morphological organs of plants. The length of the panicle increased by 9.4 - 39.2 cm depending on the rate of fertilizers.

The most important indicators of yielding capacity structure are the weight of seeds per plant and the number of plants per unit area at harvest time. It should be noted that the rates of mineral fertilizers had almost no effect on plant density, this figure was stable in terms of variants and varied between 18 and 20 plants/m^2. The mass of seeds from the plant, which varied over a wide range, had a decisive influence on the yielding capacity of amaranth. Thus, in the variant without fertilizers, it was 12.9 g, and with the application of the maximum rate of fertilizer ($N_{200}P_{80}K_{160}$) increased more than twice - to 27.8 g, or more by 14.9 g.

The weight of 1,000 seeds also grew on higher fertilizer backgrounds. In the control it was the lowest (0.86 g), and with the applicatio of the maximum rate of mineral fertilizers increased to 0.91 g.

Correlation-regression analysis has shown a very strong direct relationship between fertilizer levels and yield structure. In particular, the correlation coefficient between fertilizer levels and plant height was r = 0.93, between fertilizer levels and panicle height, seed weight of 1 plant, weight of 1000 seeds, correlation coefficient was r = 0.99, respectively. However, the correlation coefficient between fertilizer levels and plant density at the time of harvest was r = -0.26, indicating a tendency for weak feedback.

Studies have shown that fertilizers provide a significant increase of the yielding capacity. If in the control it was 2.31 t/ha, then at the highest fertilizer rate it increased by 2.57 t/ha to the level of 4.88 t/ha, i.e. more than twice (Table 2). The most effective fertilizers were applied in the second variant, as evidenced by the fact that the highest increase in yielding capacity (0.67 t/ha) was recorded during the first increase of the fertilizers rates of $N_{40}P_{20}K_{40}$. In the third variant, with the same increase of the fertilizers ($N_{40}P_{20}K_{40}$), the increase of yielding capacity also remained high - 0.56 t/ha.

Nitrogen fertilizers had the greatest impact on the yielding capacity. Application of additional N_{40} on the variants with the $N_{120}P_{40}K_{80}$ and $N_{200}P_{80}K_{120}$ fertilizer rates led to a further increase of the yielding capacity level by 0.41 t/ha and 0.34 t/ha compared to the previous variants. While increasing the rate of potassium fertilizers by K_{40} in the latter case did not provide a significant (0.04 t/ha) increase of the yielding capacity.

Table 1. Elements of the structure of the harvest of amaranth variety Kharkiv 1, the average for 2019-2021

Fertilizer rates	Plant height, cm	Panicle length, cm	Seed weight 1 plant, g	Weight 1000 seeds, g	Number of plants per m² at the time of harvest
$N_0P_0K_0$ control	147.1±6.05[a]	32.2±1.43[a]	12.9±0.65[a]	0.86±0.022	18±0.82
$N_{40}P_{20}K_{40}$	175.3±6.51[bc]	41.6±0.89[b]	15.8±0.64[bc]	0.87±0.021	19±0.82
$N_{80}P_{40}K_{80}$	188.2±7.16[bcde]	49.1±1.85[c]	17.8±0.59[c]	0.88±0.026	20±1.41
$N_{120}P_{40}K_{80}$	193.1±6.71[de]	54.1±1.17[d]	19.9±0.47[d]	0.88±0.036	20±0.82
$N_{160}P_{80}K_{120}$	199.4±4.03[dcefg]	59.3±3.70[e]	23.8±1.17[e]	0.89±0.008	19±0.82
$N_{200}P_{80}K_{120}$	208.0±4.97[fg]	71.7±1.24[f]	27.0±1.10[fg]	0.90±0.034	18±0.82
$N_{200}P_{80}K_{160}$	208,2±3.01[gef]	71.4±1.24[f]	27.8±1.24[g]	0.91±0.022	18±0.82

Values that have at least one identical letter within a table column do not differ when using the Tukey test (*P*<0.05)

Table 2. Yielding capacity of amaranth grain of variety Kharkiv 1 depending on fertilizer rates

Rate of fertilizers	Years			Average for years, t/ha	Increase to control, t/ha	Increase to previous variant, t/ha
	2019	2020	2021			
$N_0P_0K_0$ control	2.40±0.041[f]	2.01±0.043[f]	2.52±0.026[f]	2.31±0.226[f]	-	-
$N_{40}P_{20}K_{40}$	3.11±0.032[e]	2.60±0.032[e]	3.23±0.037[e]	2.98±0.287[e]	0.67	0.67
$N_{80}P_{40}K_{80}$	3.56±0.085[d]	3.21±0.067[d]	3.85±0.058[d]	3.54±0.276[d]	1.23	0.56
$N_{120}P_{40}K_{80}$	3.93±0.117[c]	3.67±0.088[c]	4.25±0.058[c]	3.95±0.256[c]	1.64	0.41
$N_{160}P_{80}K_{120}$	4.60±0.117[b]	4.20±0.047[b]	4.70±0.066[b]	4.50±0.243[b]	2.19	0.55
$N_{200}P_{80}K_{120}$	4.87±0.060[a]	4.62±0.057[a]	5.03±0.080[a]	4.84±0.194[a]	2.53	0.34
$N_{200}P_{80}K_{160}$	4.88±0.132[a]	4.71±0.059[a]	5.05±0.058[a]	4.88±0.175[a]	2.57	0.04

Values that have at least one identical letter within a table column do not differ when using the Tukey test (*P*<0.05)

Other researches have shown that the highest level of grain yield of amaranth variety Ultra provided a much higher rate of mineral fertilizers $N_{200}R_{80}K_{120}$ - 2.29 t/ha, which is 1.43 t/ha more than the control variant. The payback of a kilogram of active substance of mineral fertilizers with the yielding capacity increase was 3.56 kg (Tyrus, 2021).

Nitrogen fertilizers have the greatest effect as to the yielding capacity increase of amaranth grain (Breus, 1992; Voronin and Kotyak, 2019; Fedorchuk, 2017).

Thus, the application of an increased rate of nitrogen fertilizers - $N_{60}P_{60}K_{60}$ + N_{60-70} in a month after germination provided an increase of the average yielding capacity to 3.0 t/ha, while in the variant without fertilizers it was 2.0 t/ha (Duda and Kapshtyk, 2021).

With the application of N_{20}, the yielding capacity of amaranth grain was 0.744 t/ha, and against the background of N_{60} it increased to 1.225 t/ha (Keraliya et al., 2017). In other researches, the application of N_{20} provided the formation of grain yield at a much higher level of 3.42 t/ha, which is more compared to the variant without fertilizers by 0.36 t/ha (Voronin and Kotyak, 2019).

This equation reliably describes the process of forming the yield of amaranth variety Kharkiv 1 depending on the levels of fertilizer, which confirms the coefficient of multiple correlation (R = 0.95), between the effective feature and the argument the relationship is very close. The coefficient of determination is equal to R^2 = 0.90.

$$Y = -42.16 + 0.44\,X$$

where Y is the yield, t/ha;

X - rate of mineral fertilizers, kg d.r./ha.

CONCLUSIONS

Increasing the rate of mineral fertilizers from $N_0P_0K_0$ to $N_{200}P_{80}K_{160}$ provides an increase in the yielding capacity of amaranth grain variety Kharkiv 1 from 2.31 t/ha to 4.88 t/ha, or 2.57 t/ha. Yield depended mostly on nitrogen fertilizers, application of N_{40} on variants with the rate of $N_{120}P_{40}K_{80}$ and $N_{200}P_{80}K_{120}$ fertilizers resulted in a further increase of the yield by 0.41 t/ha and 0.34 t/ha. Increasing the potassium rate by K_{40} on variant $N_{200}P_{80}K_{160}$ did not provide a significant (0.04 t/ha) increase of the yield.

The highest level of yielding capacity is formed by the following structural elements: grain weight per plant - 27.8 g and number of plants - 18 g/m^2.

REFERENCES

Aderibigbe, O.R., Ezekiel, O.O., Owolade, S.O., Korese, J.K., Sturm, B., Hensel, O. (2022) Exploring the potentials of underutilized grain amaranth (*Amaranthus* spp.) along the value chain for food and nutrition security: A review. Critical Reviews in Food Science and Nutrition, 62 (3), 656-669. DOI: https://doi.org/10.1080/10408398.2020.1825323

Akamine, H., Ohshiro, M., Hossain, M.A. (2020) Fertilizer management for amaranth (*Amaranthus* spp.) cultivation on dark-red soil in Okinawa, Japan. Applied ecology and environmental research, 18 (6), 8145–8158. DOI: http://dx.doi.org/10.15666/aeer/1806_81458158

Asel, C. Weerasekara, Viduranga, Y. Waisundara. (2020) Amaranth as a Pseudocereal in Modern Times: Nutrients, Taxonomy, Morphology and Cultivation. DOI: https://doi.org/10.5772/intechopen.90927

Bielski, S., Szwejkowska, B. (2015) Influence of some agro-technical treatments on the development and yields of amaranth. Bulgarian Journal of Agricultural Science, 21 (No 4), 909-915. Available at: http://www.agrojournal.org/21/04-34.pdf [Accessed 08 January 2022].

Breus, I.P., Chernov, I.A., Khaibullin, L.N. (1992) Efficiency of forms of nitrogen fertilizers in the cultivation of amaranth. Agrochemistry, 11, 16-23. (in Ukrainian).

Cechin, I., Valquilha, É. M. (2019) Nitrogen effect on gas exchange characteristics, dry matter production and nitrate accumulation of *Amaranthus cruentus* L., Brazilian Journal of Botany, 42, 373–381. DOI: https://doi.org/10.1007/s40415-019-00542-1

Demidas, G.I., Sliusa, r I.E. (2019) Non-conventional fodder crops. Kyiv. NUBIP. (in Ukrainian).

Duda, O., Kapshtyk, M. (2021) Key elements of amaranth cultivation. Propozytsiia. Available at: https://propozitsiya.com/ua/klyuchovi-elementy-tehnologiyi-vyroshchuvannya-amarantu [Accessed 08 January 2022]. (in Ukrainian).

Duda, O.M. (2017) Amaranth cultivation technology. Internet Association Available at: http://amaranth-association.com/tehnologiya-viroschuvannya-amarantu/ [Accessed 01/08/2022] (in Ukrainian).

Dudka, M.I. (2019) Cultivation of amaranth paniculatus (*Amaranthus paniculatus*) in the northern steppe of Ukraine. Cereals. Dnipro, T. 3 (1), 52–61.

Fedorchuk, M.I., Rakhmetov, D.B., Kokovikhin, S.V., Fedorchuk, V.G., Filipova, I.M., Voitashenko, D.P., Rakhmetov, S.D., Kovalenko, O.A. (2017) Methodical recommendations for optimizing the technology of growing amaranth in the Southern Steppe of Ukraine. Kherson. Colossus, 25 p. (in Ukrainian).

Keraliya, S.J., Desai, L.J., Patel, S.J., Kanara, D.A. (2017) Effect of Integrated Nitrogen Management on Yield, Quality and Economic of Grain Amaranth (*Amaranthus hypochondriac* L.), International Journal of Pure & Applied Bioscience, 5 (6), 531-534. DOI: http://dx.doi.org/10.18782/2320-7051.5585

Krasnenkov, S.V., Dudka, M.I., Cherenkova, T.P. (2004) Influence of mineral fertilizers rates on seed productivity of amaranth. Feed and feed production, Vip. 53, 103 - 106. (in Ukrainian).

Makinde, E.A., Ayeni, L.S., Ojeniyi, S.JO. (2011) Effects of Organic, Organomineral and NPK Fertilizer Treatments on The Nutrient Uptake of *Amaranthus Cruentus* (L) on Two Soil Types in Lagos, Nigeria. Journal of Central European Agriculture, 12 (1), 114-123. DOI: https://doi.org/10.5513/JCEA01/12.1.887

Martínez-Villaluenga, C., Peñas, B., Hernández-Ledesma. (2020) Pseudocereal grains: Nutritional value, health benefits and current applications for the development of gluten-free foods. Food and Chemical Toxicology, 137, 111178. DOI: https://doi.org/10.1016/j.fct.2020.111178

Olofintoye, J.A.T., Abayomi, Y.A., Olugbemi, O. (2015) Yield responses of grain amaranth (*Amaranthus cruentus* L.) varieties to varying planting density and soil amendment. African Journal of Agricultural Research, 10 (21), 2218-2225 DOI: https://doi.org/10.5897/AJAR2015.9746

Parmar, J.K., Patel, J.J. (2008) Effect of nitrogen management on growth and yield of grain amaranthus (*Amaranthus hypochondriacus* L.) grown on loamy sand soil. Asian Journal of Soil Science, 4 (1), 106-109. Available at: http://researchjournal.co.in/upload/assignments/4_106-109.pdf [Accessed 01/08/2022].

Petrichenko, V.F., Likhochvor, V.V. (2021) Plant growing. New technologies for growing field crops: a textbook. 5th ed., Corrected, supplemented. Lviv. Scientific and Production Enterprise "Ukrainian Technologies". 806 p. DOI: https://doi.org/10.31073/roslynnytstvo5vydannya

Pospišil, A., Pospišil, M., Varga, B., Svečnjak, Z. (2006). Grain yield and protein concentration of two amaranth species as influenced by nitrogen fertilizer. European Journal of Agronomy, 25 (3), 250-253. DOI: https://doi.org/10.1016/j.eja.2006.06.001

Rakhmetov, D., Rybalko, J. (2005) Amaranth again reminds of himself. Propozytsiia, 2, 67 - 68. (in Ukrainian)

Saratovsky, L.I., Saratovsky, A.L. (2014) Cereal and fodder amaranth. Monograph. under ed. VA Fedotov. Voronezh. Voronezh. state agrarian, un-t. 254 p.

Sarker, U., Oba, S. (2020) Nutritional and bioactive constituents and scavenging capacity of radicals in *Amaranthus hypochondriacus*. Scientific Reports, 10, 19962. DOI: https://doi.org/10.1038/s41598-020-71714-3

Savchuk, O.I., Gurelya, V.V., Koshytska, N.A., Black, A.G. (2016) Efficiency of amaranth cultivation in the Polissya zone. Collection of scientific works Agro-industrial production of Polissya. Vip. 9, 36-39. Available at: http://nbuv.gov.ua/UJRN/avpol_2016_9_9 [Accessed 08 January 2022].

Skwaryło-Bednarz, B., Brodowska, M.S., Onuch, J., Sapuła, J. (2014) Plonowanie krajowych odmian szarłatu (*Amaranthus cruentus* L.) w warunkach zróżnicowanego nawożenia makroelementami. Annales UMCS, sec. E. Agricultura, 69 (2), 37-43.

Skwarylo-Bednarz, B., Stepniak, P.M., Jamiolkowsra, A., Kopacki, M. (2020) The amaranth seeds as a source of nutrients and bioactive substances in human diet. Acta scientiarum Polonorum. Hortorum cultus, 19 (6), 153-164. DOI: https://doi.org/10.24326/asphc.2020.6.13

Śmigerska, K. (2016) Badania nad doskonaleniem uprawy na nasiona szarłatu krwistego (*Amaranthus cruentus* L.) odmiany Rawa. Bydgoszcz. Uniwersytet Technologiczno-Przyrodniczy im. J.J. Śniadeckich. 137. Available at: http://dlibra.utp.edu.pl/Content/958/SmigerskaKarolina_BADANIA_NAD_DOSKONALENIEM_UPRAWY_NA_NASIONA_SZARLATU-1-1.pdf [Accessed 01 August 2022].

Tabrizi, E.F.M., Yarnia, M., Rashidi, V., Rahimzadeh, K.F., Khorshidi, B.M.B. (2013) Effect of nitrogen and micro fertilizer application on the yield of amaranth (*Amaranthus hypochondriacus* L.×*Amaranthus hybridus* L.) cv. Koniz. Research on Crops, 14(3), 711-715. Available at: https://www.researchgate.net/publication/287586176_Effect_of_nitrogen_and_micro_fertilizer_application_on_the_yield_of_amaranth_Amaranthus_hypochindriacus_L_Amaranthus_hybridus_L_cv_Koniz [Accessed 01 August 2022].

Tayade, M.S., Bawkar, S.O., Kale, V.S. and Deshmukh, U.B. (2012). Integrated nutrient management in amaranthus (*Amaranthus tricolor* L.). Asian Journal of Horticulture, 7 (2), 291-293.

Tyrus, M.L. (2021) Influence of fertilizer levels on amaranth productivity in Western Forest-Steppe conditions. Bulletin of Lviv National Agrarian University: agronomy, №25, 63-65. DOI: https://doi.org/10.31734/agronomy2021.01.063

Ulicny, A., Duranik, T., Koszel, M. (2013). Technology of soil bioremediation and conversion of contaminated phytomass into usable energy forms. Journal of Central European Agriculture, 14 (3), 1029-1038. DOI: https://doi.org/10.5513/JCEA01/14.3.1300

Voitashenko, D.P. (2005 a) Influence of moisture conditions and mineral nutrition level on amaranth grain yield in the southern steppe. Collection of scientific works. Irrigation agriculture. Institute of Agriculture of the Southern Region of UAAS. Kherson. Island. Vip. 44, 45-49. (in Ukrainian).

Voitashenko, D.P. (2006 b) Productivity of amaranth of grain direction depending on moisture conditions and rates of mineral fertilizers. Collection of scientific works. Irrigation agriculture. Institute of Agriculture of the Southern Region of UAAS. Kherson. Island. Vip. 45, 48-52. (in Ukrainian).

Voronin, A.N., Kotyak, P.A. (2019) Influence of nitrogen fertilizer dose and width of interrows on amaranth productivity. Agrarian Bulletin of the Upper Volga Region, 3 (28), 11-16. DOI: https://doi.org/10.35523/2307-5872-2019-28-3-11-16

Zadorozhna, I.S. (2011) From the history of research of uncommon forage crops in Ukraine. Available at: http://base.dnsgb.com.ua/INB/2011-3/11_zadorozhna.pdf [Accessed 08 January 2022].