Polish Journal of Agronomy
2021, 46, 40-48

doi: 10.26114/pja.iung.466.2021.47

Nutritional value and potential uses of amaranth seeds and the outlook to increase the area under the amaranth crop in Poland

Marcin Różewicz

Department of Cereal Crop Production
Institute of Soil Science and Plant Cultivation – State Research Institute
ul. Czartoryskich 8, 24-100 Puławy, POLAND

Abstract. *Amaranthus* L. belongs to herbaceous plants with C4-type photosynthesis. The genus *Amaranthus* contains about 70 species, with three subspecies, including both cultivated and wild types. Amaranth, a pseudo-cereal, has been known to mankind for quite some time and is one of the oldest cultivated plants in the world. It originates from South America, where its cultivation began and where its seeds and green parts were used as food for humans and animals. Nowadays, it is grown in many countries of the Americas, Southeast Asia and Africa. In Europe it is a plant whose cultivation and utilization potential remains underappreciated. The seeds are gluten-free and contain the valuable health-promoting compound squalene along with tocopherols and carotenoids. As the amaranth seeds have exceptional nutritional qualities, the crop should be cultivated in Europe. Both the seeds and the green parts of amaranth can also be successfully used in animal nutrition. They contribute valuable protein, fat and macro- and microelements to the feed. As evidenced by previous scientific research, amaranth can be grown in Poland. It is currently grown on a small scale, but the varied potential uses of the grain offer a good prospect for a significant increase of the area under that crop in Poland. Only two cultivars are currently available for cultivation in Poland so there is much demand fort further breeding work aimed at developing new cultivars adapted to the coutry's climate. The aim of the study is to discuss the nutritional value and possibilities of cultivation development and use of amaranth seeds in Poland

Keywords: amaranth, cultivation of amaranth, nutritional value, fodder value

INTRODUCTION

Amaranth is one of the oldest cultivated plants. It comes from South America, and the nutritional value of its seeds became known to Europeans after the discovery of this land. Much earlier it was a highly esteemed plant cultivated by the indigenous inhabitants of America, including the Incas, Mayans and Aztecs. Amaranth seeds ground into flour were used by South American Indian tribes to prepare meals (tortillas and drinks). In addition to the seeds themselves, the leaves and young shoots of this plant were also valued as a vegetable and spice. Originally, after amaranth was brought to Europe, it was grown as an ornamental plant, but later its seeds came to be used as food (Adhikary et al., 2020). Mueller-Bieniek et al. (2015) found amaranth remains near Kraków dating to the 13th century, which indicates a fairly early cultivation of the plant in Poland, but the researchers believe that the plant was grown as an ornamental rather than a utilitarian. However, the period of high interest in amaranth was followed by a decline in its cultivation. In Poland, the waning interest in amaranth could have been caused by the lack of a sales market, as a result of little interest on the part of companies processing grain for food and fodder purposes. The small number of available cultivars, Rawa and Aztek, could also discourage cultivation. In addition, there was also little research in management practices of amaranth, and in particular on the appropriate sowing date under Poland's climate. Currently, however, due to the increased interest in healthy food with increased nutritional value, there is a renewed interest in the cultivation and use of amaranth. In Poland, the largest concentration of amaranth production fields is located in the Lublin region and in southern Poland due to the most favourable conditions for its cultivation. In those regions, the area sown to amaranth accounts for about 90% of the total area under this crop in Poland (Ogrodowska et al., 2011). According to the latest data available for Poland, the acreage cropped to amaranth was reported to be 100 ha (Kozak et al., 2011). It is worth noting that despite the growing interest in amaranth, the seeds of which have gained much popularity, and as a result of the positive results of using them in animal nutrition, in Poland the potential of this plant has not been fully exploited, and the scale of cultiva-

Corresponding author:
Marcin Różewicz
e-mail: mrozewicz@iung.pulawy.pl
phone: +48 81 4786 818

tion is also relatively small. Increasing the acreage under cultivation could result in a greater supply of amaranth seeds and their wider use in the feed industry. Amaranth belongs to plants with type C4 photosynthesis (Adhikary et al., 2020). The advantage of C4 plants is that they achieve satisfactory yields having at the same time a low demand for water and resistance to drought stress (Jamalluddin et al., 2019). This makes amaranth drought-tolerant and at the same time able to thrive on relatively poor soils. It is therefore a plant that can be successfully grown on conventional farms, but especially on organic farms. The main group of recipients of the seeds are health food stores, whose clients are people who are particularly interested in the organic products. Two cultivars of amaranth are available in Poland: Rawa (light green inflorescences) and Aztek (dark maroon inflorescences) (Skwaryło-Bednarz et al., 2018). The high nutritional value of the seed will achieve the presence carbohydrate, macro, and high content of the presence in the seed that are present in the human diet. Therefore, it is worth promoting the cultivation of Amaranth and increasing its acreage, which will contribute to supplying people with valuable food raw material, which are seeds. As a gluten-free seed, amaranth can be used in the diet of people with gluten intolerance. The possibility of using it in animal nutrition is an additional advantage which speaks in favuor of the popularization of the cultivation of amaranth in Poland.

NUTRITIONAL VALUE OF AMARANTH SEEDS

Amaranth seeds are among the smallest seeds of those produced by cultivated plants grown in Poland. Their size depends on the variety and cultivation conditions. Their 1000 seed weight ranges from 0.64 to 0.79 g (Ogrodowska et al., 2011). This parameter refers to the formation of seeds, more specifically to 1000 grain weight. The higher this parameter, the better quality the seeds are. Their unique nutritional value is associated with high protein content – with higher digestibility and lack of gluten (Alvarez-Jubetea et al., 2010; Ballabio et al., 2011). Therefore, they are a valuable addition to the diet of people with gluten intolerance. Additionally, the starch contained in them is easier to digest (Srichuwong et al., 2017). Amaranth seeds contain a significant amount of protein, the content of which in the seeds ranges from 13.5 to 18% (Gajewska et al., 2002; Bartnik, Filipek, 1999). Compared to the protein content of the grain of cereals or other pseudo-cereals, it has a higher, comparable or higher protein content. Only canary seed and qinoa have more protein in the grain (Table 1).

Table 1. Comparison of protein content in the grain of different types of cereals and pseudo-cereals.

Cereal species		Protein content [%]	Author
Cannary grass		22.0	Abdel-Aal et al., 2011 Abdel-Aal et al., 1997
Wheat	spring	13.5–14.1	Woźniak and Makarski, 2013
	winter	10.5–13.8	Oleksy et al., 2008
Oat	hulled	11.5	Biel et al., 2020
	nacked	14.4	
Barley	spring	10.8–12.0	Noworolnik and Leszczyńska, 2018
	winter	11.1–12.1	Chrzanowska-Drożdż and Kaczmarek, 2007
Rye		8.8–10.5	Buksa et al., 2012 Noworolnik, 2009
Corn		9.1–12.7	Podkówka et al., 2015
Millet		8.5–15.0	Abdalla et. al., 1998
Sorghum		8.7–11.2	Salinas et, al., 2006
Amaranth		**13.5–18.0**	Gajewska et al., 2002 Bartnik and Filipek, 1999
Quinoa		22.0	Sułkowski et al., 2011

The effect on total protein content in seeds is related to nitrogen fertilization. Increased nitrogen rate contributes to an increase in seed protein content (Kozak et al., 2011). This protein has a very good biological value and is abundant in essential amino acids. The amaranth protein consists mainly of albumin (48.9–65%), globulins (13.7–18.1%), prolamins (1.0–3.2%) and gluteins (22.4–42.3%) (Gálová et al., 2019). The amino acid profile includes glutamic acid, glycine, aspartic acid, serine and arginine (Mynbayeva, Dryuk, 2020). In addition, it also contains a relatively high content of lysine and sulfur amino acids, and other amino acids which are deficient in cereal protein (Kaźmierczak et al., 2011). The high biological value of amaranth seed protein is also associated with its high assimilability, which is 75% of total protein (Nalborczyk, 1995). Amaranth seeds are also distinguished by a relatively high fat content (about 7–9%) (Ratusz, Wirkowska, 2006; Piłat et al., 2016), whose fatty acid profile is dominated by linoleic (49.7%), oleic (25.9%) and palmitic acids (16.1%) (Ratusz, Wirkowska, 2006). However, the composition of fatty acids in oil obtained from amaranth seeds depends on the varietal factor, as well as weather conditions during the growing season and the level of nitrogen fertilization (Kozak et al., 2011). A unique component of the lipid fraction of amaranth seeds is squalene, which, depending on the variety, is found in amounts ranging from 2 to as much as 8% (Srivastava et al., 2021). This compound found in amaranth fat inhibits the activity of a major enzyme in cholesterogenesis and further inhibits intestinal absorption of bile acids and cholesterol (Qureshi et al., 1996). Amaranth seeds also contain a significant amount of carbohydrates, (total 62.8%,) with starch accounting for 50%. It is characterized by high digestibility due to very small grain diameter (1–3 μm). In comparison with wheat grains, amaranth seeds contain less carbohydrates, but 2.5 times more fibre, which is beneficial from a dietary point of view (Al-Dosari, 2010). Amaranth seeds are also a valuable source of micro and macroelements. They contain iron (10.1 mg/100 g) and calcium (153 mg/100 g), which is important from the nutritional point of view, providing several times more of these elements than cereal grains. Hundred g of amaranth seeds contains: of potassium 341.9 mg, 65.87 mg of magnesium, 0.91 mg of zinc (Kachiguma et al., 2015). According to the study conducted by Gajewska et al. (2002) consumption of 100 g of amaranth seeds satisfies the daily requirement for manganese (they provide from 126 to 227%), nickel (from 61 to 584%), potassium (from 79 to 158%), iron (from 53 to 97%), copper (from 42 to 193%), chromium (from 14 to 110%) and zinc and calcium (from 9 to 69%). At the same time, amaranth seeds contain low levels of sodium, which predisposes the introduction of amaranth seeds into the diet for people with excess weight and hypertension. The seeds are also rich in vitamin B_6, thiamine, riboflavin and niacin. They also contain tocols, of which α-tocopherol and β-tocotrienol and γ-tocotrienol are the most abundant (Niro et al., 2019). Amaranth seeds also contain polyphenolic compounds with a content of 0.19% (Piłat et al., 2016). Amaranth seeds also contain compounds of an anti-nutritional nature. These include trypsin and chymotrypsin inhibitors, tannins, phytins, saponins, and other compounds that reduce food and feed value. The content of trypsin inhibitors varies in particular foods. This is because they are thermolabile compounds. Heat treatment causes their deactivation. Therefore, the highest content is found in unprocessed seeds and flour – about 1.66 mg/g d.m. A lower content is found in seeds subjected to the flaking process – 1.10 mg/g d.m. On the other hand, seeds subjected to the expansion process resulting in popping contain 0.25 mg/g d.m. of trypsin inhibitors (Worobiej et al., 2009). Compounds from the saponin group found in amaranth seeds are mainly triterpene glycosides. However, their content is so low that they do not show high harmfulness to the organism. Their content is at the level of 0.1% in the dry matter of seeds (Jakuszew, 1997).

FOOD USE OF SEEDS

Recent years have seen a significant increase in the number of people who pay much more attention to a balanced diet and seek products with increased nutritional and health value. This trend includes amaranth seeds, which exhibit a high content of nutrients, macro- and microelements, as well as important dietary fibre. With so many advantages, these seeds are increasingly used as an additive to many food products. One of the most popular forms of amaranth seeds used as a snack is a popping, i.e. seeds subjected to the process of expansion. The seeds are also used to produce flour, which can be added to bread and other baked goods. Flour from amaranth contains similar amounts of nutrients and micro- and macroelements as the seeds (Table 2).

Due to the fact that the flour obtained from the seeds is a valuable addition to baked goods, it is used in baking and confectionery. Added to bread, amaranth seed flour improves its nutritional value and contributes to an increased intake of important components of the daily diet. It is recommended to add a maximum of 10% of amaranth flour or flakes to bread. Exceeding this value causes a negative effect on the sensory characteristics of baked bread (Nasir et al., 2020). It is also possible to use amaranth flour in gluten-free bread recipes. Bakery products with addition of 25% amaranth flour, 25% rice flour and 50% maize flour develop the most favourable features of baked bread, including porosity, good rise and taste (Cacak-Pietrzak et al., 1995a). In this way, it is possible to address the market with a suitable type of bread for people suffering from coeliac disease and those who limit their gluten intake. This will enrich and diversify the range of bread available. Flour from amaranth and its seeds can also be used to make confectionery products. When whole seeds are used, it is preferable to roast them, which gives the products their beneficial characteristics. The use of 10 and 15% addition of roasted seeds had a beneficial effect on the taste, giving the products a nut and coffee flavor (Cacak-Pietrzak et al., 1995b). The use of 10% and 15% addition of amaranth flour does not decrease sensory evaluation of baked cookies and does not cause adverse changes in their chemical composition of cookies (Sosnowska, Achremowicz, 2000). The possibilities of using amaranth seeds in the production of pastry products are very wide. Cakes containing amaranth seeds in their recipe composition can successfully replace traditional products. Their taste is acceptable by consumers and comparable to traditional cookies, but they have a higher nutritional value (Klebaniuk et al., 2018). They can be used as an additive in the production of snacks in the form of crisps. The addition of amaranth seeds to the composition of corn crisps resulted in higher intensity of cereal, sweet, and chocolate flavours (Gajewski et al., 2015). Amaranth seeds, due to their high nutritional value can also be a valuable addition to yoghurt (Sady et al., 2007). The range of products with added amaranth seeds is very large. However, their declared nutritional value on packages and labels may differ from the actual nutritional and dietary value (Klebaniuk et al., 2018). The reason may be the high variability of the starting raw material, which is amaranth seeds. Very fragmented plantations of this crop and small scale of production result in delivery of small batches of raw material with very different composition.

Due to the very favourable fatty acid composition of the fat and squalene content of amaranth seeds, they can also be used for the production of vegetable oil. The oil extracted from them can be used in the diet. Its inclusion in the diet has a health-promoting effect through a number of actions. These include regulation and stabilization of blood lipid profile and lowering of blood pressure, as well as antiatherogenic and hepatoprotective effects (Moszak et al., 2018).

Table 2. Content of nutrients, vitamins and minerals in amaranth products and wheat grain (Gajewska et al., 2002; Abdel-Aal et al., 2011).

Component	Amaramth			Wheat kernel
	Seeds	Flour	Popping	
Protein (g/100 g)	13.5	13.1	1.4	-
Fat (g/100g)	7.1	7.2	7.6	-
Total carbohydrates (g/100 g)	68.3	65.8	71.7	-
Starch (g/100 g)	54.3	55.7	56.6	-
Fibre (g/100 g)	4.7	5.3	4.2	-
Thiamine (µg/100 g)	29.0	29.0	19.0	4.0
Riboflavin (mg/100 g)	0.131	0.100	0.143	0.15
Niacin (mg/100 g)	1.02	1.14	1.20	7.29
Vitamin B_6 (mg/100 g)	0.563	0.615	0.586	
Calcium (mg/100 g)	223	204	212	20
Phosphorus (mg/100 g)	738	712	792	430
Iron (mg/100 g)	8.3	9.3	9.7	4.2
Magnesium (mg/100 g)	218	200	235	155
Zinc (mg/100 g)	2.9	3.1	3.1	2.5
Copper (mg/100 g)	1.03	1.19	1.38	
Manganese (mg/100 g)	4.54	4.36	3.78	5.9
Sodium (mg/100 g)	6.30	7.93	8.42	
Potassium (mg/100 g)	337	318	331	355
Chromium (mg/100 g)	0.040	0.041	0.55	-
Nickel (mg/100 g)	0.292	0.217	0.185	-
Cobalt (mg/100 g)	0.045	0.050	0.051	-

FEED USE OF SEEDS

Due to the high nutritional value of amaranth seeds, the possibility of their use in poultry nutrition has aroused the interest of many researchers. At the same time, due to the presence of anti-nutritional substances, hindering the effective use of nutrients, research has also been conducted on the use of raw seeds and their maximum possible share in feed mixtures for different poultry species, but also on the possibility of using seeds subjected to various refining treatments. Banaszkiewicz (2004) conducted research on the possibility of using different proportions of raw and steamed amaranth seeds in feed for broiler chickens. For this purpose, the author used a control diet with a basic cereal component (wheat) and four experimental groups with 10 and 20% share of raw and steamed amaranth seeds, which were substituted for part of the share of wheat in the feed. According to the author, the use of 20% amaranth seeds, both raw and steamed, resulted in a better utilization of protein up to 3%. However, the substitution of 10% of wheat with steamed amaranth seeds resulted in an increase in protein digestibility by 1.5% compared to the control and experimental diets with a 10% share of raw amaranth seeds. Fat contained in the steamed seeds, was significantly better digested than that from raw seeds by 5%. The results of studies by many other authors indicate the advisability of using various refining treatments such as toasting, roasting or cooking for amaranth seeds (Pedersen et al., 1990). Faruga and Mikulski (1998) conducted a study on the possibility of using amaranth seeds in the feeding of broiler chickens and laying hens. The researchers substituted 13% amaranth seed for wheat grain in feed mixes for laying hens and broiler chickens, respectively. The introduction of amaranth in chicken mixes did not adversely affect production performance, while better slaughter performance was observed. In addition, in biochemical blood tests, lower levels of lipids and total cholesterol were noted in the blood of chickens receiving feed with amaranth. At the same time, the results obtained were within the physiological norm. Jakubowska et al. (2013) used amaranth seeds as a feed component for slaughter quail. The experimental groups used 4 and 7% share of seeds of this plant in feed. The authors showed no effect of seed application and level on chemical composition and physical properties of pectoral and leg muscles. There was also no effect of the application of amaranth seed and its level in the feed on the fatty acid profile compared to the control group. In the sensory evaluation, pectoral muscles obtained from quail from the group receiving feed with 4% amaranth were characterized by better tenderness compared to the group receiving 7% amaranth addition and the control group. Longato et al. (2017) using the addition of amaranth seed with flaxseed oil obtained a very favourable fatty acid profile in the muscles of broiler chickens, while retaining a significant amount of antioxidants, without affecting other meat quality traits. In the case of laying hens, the 13% proportion of flaked amaranth seeds in the feed proved to have a negative effect, thus lowering the laying rate by 4–7% in the experimental group compared to the control, but with no negative effect on the quality of the eggs obtained. The results of this study may indicate that too high a proportion of amaranth was used in the mix fed to laying hens. However, completely different production results for laying hens were obtained by Tillman and Waldroup (1987). During a 6-week study, hens received feeds with varying amaranth seed percentages: 0, 10, 20 i 30%. The authors found that the use of amaranth seed in feed resulted in a slight increase in laying performance with its higher proportion, but they were characterized by significantly lower weights. In addition, layers were characterized by lower daily feed intake. Reklewska et al. (1995), used a much lower proportion of amaranth seed meal, 6%, which had the higher content of unsaturated fatty acids in the yolk, while lowering the content of saturated fatty acids. Thus, these eggs had a very favourable fatty acid profile from the consumer's point of view, which translates into their more favourable nutritional and health-promoting qualities. In recent years, cholesterol has become a reason for excluding eggs from the diet of many people. In this context, the results obtained by Bartkowiak et al. (2007) seem promising. The authors used feed enriched with 5% amaranth seed in the feeding of laying hens. The use of this addition proved to have a beneficial effect on the dietary value of eggs. A significant increase in vitamin A content was observed in the eggs, while total cholesterol content in the yolks decreased. This could be due to compounds contained in amaranth seeds such as: saponin, squalene, and a certain proportion of fibre. These substances contribute to an increase in the excretion rate of endogenous cholesterol, which translates into its lower concentration in the blood of laying hens and proportionally lower deposition of this compound in egg yolk. An additional advantage was the confirmation of a change in the fatty acid profile of the yolk, due to a much higher proportion of unsaturated fatty acids. Cholesterol-reduced eggs may therefore be an important offering to people who need to consume a diet as low in cholesterol as possible. The steadily growing number of people who have problems with high blood cholesterol levels (resulting in atherosclerosis) is becoming a disease of civilization. Punita and Chaturvedi (2000) indicate that by using a variant of feed formulation based on amaranth seed for laying hens, even lower cholesterol levels can be achieved. The feed composition for laying hens used by the authors additionally influenced the higher content of polyunsaturated fatty acids (PUFA) in the yolk. Popiela et al. (2013), on the other hand, used extruded amaranth seeds in the feeding of laying hens. Laying hens were divided into three groups: a control group and two experimental groups with 5 and 10% addition of extruded amaranth seed. The authors found no differences in mean egg weight, shell strength and protein quality parameters. Sensory analysis of the eggs showed no differences between the groups. However, the researchers recommend a 5% proportion of extruded amaranth seed in laying feed. In the research carried out by Króliczewska et al. (2008), the obtained result was that feeding laying hens on diet supplemented with amaranth grain did not negatively influence the selected haematological parameters of blood. Moreover, the generally beneficial influence of applying the amaranth seed on the lipid parameters of birds blood was observed.

Amaranth seeds are also used in pig nutrition. Their addition improves the health of animals. Due to the high biological value of the protein contained in the seeds of amaranth, they are a beneficial component of protein feed for this group of animals (Zralý et al., 2004).

AMARANTH CULTIVATION IN POLISH CLIMATIC CONDITIONS

Most of the among 70 different Amaranth species are native to South America (about 50 species) where the climate is relatively warm and humid (Suresh et al., 2014). Nevertheless, it is a plant that adapts quite well to different climatic conditions. Some of the other 15–20 species of amaranth originated in Asia, Europe and Africa (Das, 2016). This high genetic diversity makes it possible to cross individual species with each other in order to obtain new plant varieties that adapt easily to new growing conditions and offer the possibility of being used for growing for seeds and green matter (Stetter et al., 2016; Stetter, Schmid, 2017). Thanks to considerable genetic diversity and the possibility of adapting varieties to climatic conditions and the purpose of cultivation (for seeds or green matter), the geographical range of amaranth cultivation has spread considerably to different regions of the world, including Africa, Asia and Europe.

There are few studies on the possibility of cultivating amaranth under Poland's climate conditions. A study on the possibility of growing amaranth was conducted over two growing seasons by Kozak et al. (2011). The authors tested two cultivars of amaranth (Aztek and Rawa), which were fertilized with different levels of nitrogen divided into doses at different stages of plant growth (60 – before sowing; 60 – before sowing + 30 in the shoot formation phase; 60 – before sowing + 30 in the shoot formation phase + 30 in the inflorescence formation phase). According to the authors cited above, increasing nitrogen fertilization contributed to an increase in the values of some morphological characteristics of plants, such as plant height and inflorescence setting, inflorescence length, as well as seed yield components, such as: seed weight per 1 plant, as well as total seed yield and seed quality characteristics, such as fat and protein content in seeds. The results obtained by Kozak et al. (2011) showed that the cultivar Aztek, compared to Rawa, was characterized by higher values of the above indicators. Under Poland's climate conditions, sowing of amaranth should be carried out at the beginning of May due to high thermal requirements during the emergence period. Emergence occurs up to 12–14 days after sowing. Weather conditions are of great importance both for the yield and the quality of the obtained seed yield. This is confirmed by the research by Biel et al. (2017), where, according to the cited authors, the influence of favourable weather conditions that occurred in the growing season of 2014, was demonstrated in a one-year experiment. Different cultivars may have different thermal requirements during the emergence period. A study by Dziwulska-Hunek and Kornarzyński (2009) showed that the germination capacity of amaranth seeds of the cultivar Aztek was optimal in the range of 20–25 °C, while another cultivar, Rawa, had the highest germination capacity at 20 °C. Jendrzejczak and Śmigerska (2014) found a higher germination capacity of seeds of the Rawa at 25 ^{o}C. According to these researchers, the germination capacity of seeds at the temperature lower than 15^{o} C can be increased by soaking them for 8 h in a 0.03% aqueous solution of Pol-Gibrescol, or in a mixture of a 0.03% solution of Pol-Gibrescol preparations and a 2% of Betoxone 0,25. Seeds of both varieties have a low germination capacity at 10 °C. The temperatures favouring the germination of amaranth seeds, i.e. above 10 ^{o}C, occur in the Polish climate, based on the last two decades, from the beginning of May (Górski, Kozyra, 2011). The flowering phase of plants starts at 49–52 after sowing, while full seed maturity is reached at 178–190 days after sowing (Kozak et al., 2011). The length of individual phases depends on the temperature during the growing season, while the optimum range is considered to be 26–28 °C, while growth and development occur at temperatures ranging from 16 °C to 35 °C (Dziwulska-Hunek, Kornarzyński, 2009). The date of sowing and harvesting depends on climatic conditions and the purpose of cultivation (for seeds or green matter), which also determines the appropriate crop management techniques and level of fertilization. Ziernicka-Wojtaszek (2015) found that the regions, classified as very warm, of the increased from 10 to 48% of Poland's total area, and the dry zone, with the value of the climatic water balance ranging from -90 to -120 mm, from 34 to 52% of Poland's territory. The area of a very warm and dry region increased sixfold – from 5% in the 1971–2000 period to 30% in 1981–2010. Increasing temperatures and the associated lengthening of the growing season predispose the introduction of thermophilic crops (Kopeć, 2013). In this context, the introduction of new cereal species into cultivation in Poland may be beneficial. As in the case of sorghum and maize, two groups can be distinguished among amaranth varieties: those grown for hay/green matter and seed. According to the research conducted by Dmitrieva and Ivanov (2020), *Amaranthus cruentus* and *Amaranthus caudatus*, which show high growth of green matter with similar fodder value during 100 days of vegetation, are more suitable for green matter cultivation in European conditions. For amaranth grown for seeds, by resorting to marker-assisted selection it is possible to successfully breed cultivars that are efficient in terms of seed yield and adapted to full generative development under European climate conditions, (Stetter et al., 2016).

The cultivation of amaranth, in addition to the benefits obtained from the yield of seeds and green matter, is also desirable for crop management-related reasons. Introducing a new plant into the rotation, for cultivation in Poland, where cereal cultivation dominates nearly 75% of the area used for sowing arable crops, can increase the diversity of plants in the crop rotation. In addition, as shown by Skwaryło-Bednarz (2008), soil under amaranth cultivation, due to the root secretions of this plant, is characterized by high biological activity expressed by the number of microorganisms and the activity of examined enzymes, i.e. dehydrogenase and catalase. However, the researcher noticed cultivar-related differences. She found a higher number of bacterial and actinomycete colonies and a higher activity of the examined enzymes in the soil under Aztek vis-à-vis Rawa. However, the soil environment under Rawa was colonized by fungi to a greater extent.

SUMMARY

The changing climate and the ever-longer growing season favor the cultivation of amaranth in Poland. Despite the fact that it was possible to cultivate this plant in Poland earlier, the scale of cultivation was small. However, there is a potential for the development of amaranth cultivation in Poland, especially since the nutritional value of its seeds makes it possible to use it in both human food and animal feed. Due to its unique nutritional properties, amaranth seeds are a valuable source of many nutrients especially squalen, which is found in large amounts in the seeds of this plant. Their high fodder value also makes them a valuable feed component. The addition of amaranth seeds to animal feeds introduces a certain amount of protein, energy in the form of fat and easily digestible starch and micronutrients. The high nutritional value of amaranth seeds results in their beneficial effect on the quality as well as dietary and health-promoting value of animal products. The outlook to increase the area under Amaranth in Poland is dependent on field extension work aimed at counselling amaranth growers on issues related to the date of sowing, fertilizing and harvesting plants. Equally important is to establish a permanent outlet for the harvested seeds. Therefore, in order to increase the cultivation area of amaranth in Poland, cooperation between farmers and grain recipients, such as companies producing food for people and companies producing animal feed, should be increased. The organic cultivation of amaranth is one of the ways of increasing its growing area and producing of its seeds in Poland.

The possibility of further expansion of the area cropped to amaranth should also be supported by breeding new cultivars, adapted to the soil and climatic conditions of Poland, and high-yielding.

REFERENCES

Abdalla A., Tinay El A.,. Mohamed A.H, Abdalla B.E. 1998. Proximate composition, starch, phytate and mineral contents of 10 pearl millet genotypes. Food Chemistry, 63: 243-246.

Abdel-Aal E.S.M., Hucl P.J., Shea S., Miller-Patterson C.A., Gray D., 2011. Microstructure and nutrient composition of hairless canary seed and its potential as a blending flour for food use. Food Chemistry, 125: 410-416, doi: 10.1016/j.foodchem.2010.09.021.

Abdel-Aal E.S.M., Hucl P.J., Sosulski F.W., 1997. Structural and compositional characteristics of canaryseed (*Phalaris canariensis* L.). Journal of Agricultural and Food Chemistry, 45: 3049-3055.

Adhikary D., Khatri-Chhetri U., Slaski J. 2020. Amaranth: an ancient and high-quality wholesome crop. In: Nutritional Value of Amaranth. IntechOpen. https://books.google.pl/books?hl=pl&lr=&id=Rkv9DwAAQBAJ&oi=fnd&pg=PA57&dq=amaranth+Dinesh&ots=g7nFQlSBt6&sig=wc8PBLio9wDCsIBrYJ7Y6zNahzo&redir_esc=y#v=onepage&q=amaranth%20Dinesh&f=false

Al-Dosari M.S. 2010. The effectiveness of ethanolic extract of *Amaranthus tricolor* L.: A natural hepatoprotective agent. The American Journal of Chinese Medicine, 6(38): 1051-1064.

Alvarez-Jubete L., Wijngaard H., Arendt E. K., Gallagher E., 2010. Polyphenol composition and in vitro antioxidant activity of amaranth, quinoa buckwheat and wheat as affected by sprouting and baking. Food Chemistry, 119(2): 770-778, doi: 10.1016/j.foodchem.2009.07.032.

Ballabio C., Uberti F, Di Lorenzo C., Brandolini A., Penas E., Restani P., 2011. Biochemical and immunochemical characterization of different varieties of Amaranth (*Amaranthus* L. ssp.) as a safe ingredient for gluten-free products. Journal of Agricultural and Food Chemistry, 59: 12969-12974.

Banaszkiewicz T., 2004. Nutritive value of raw and steamed amaranth seeds for broiler chickens. Roczniki Naukowe Zootechniki, 20: 161-164. [in Polish + summary in English]

Bartkowiak A., Skiba T., Króliczewska B., 2007. Level of selected lipid fractions in egg yolk of hens fed with fodders supplemented with amaranth seeds. Polish Journal of Food and Nutrition Sciences, 57(4): 3-6.

Bartnik M., Filipek A., 1999. Research on selected indicators of the nutritional value of amaranth seeds and leaves. Żywienie Człowieka i Metabolizm, 3(26): 229-241. [in Polish + summary in English].

Biel W., Jendrzejczak E., Jaroszewska A., Witkowicz R., Piątkowska E., Telesiński A., 2017. Nutritional content and antioxidant properties of selected species of *Amaranthus* L. Italian Journal of Food Science, 29(4): 728-740.

Biel W., Kazimierska K., Bashutska U., 2020. Nutritional value of wheat, triticale, barley and oat grains. Acta Scientiarun Polonorum Zootechnica, 19(2): 19-28.

Buksa K., Nowotna A., Gambus H., Krawontka J., Sabat R., Noga M., 2012. Technological evaluation and chemical composition of rye grains of selected varieties cultivated by 3 consecutive years. Acta Agrophysica, 19(2): 265-276. [in Polish + summary in English]

Cacak-Pietrzak G., Dojczew D., Haber T., Lewczuk J., 1995a. Pieczywo bezglutenowe z dodatkiem mąki z amarantusa. Żywność Technologia Jakość, 2: 121-122.

Cacak-Pietrzak G., Dojczew D., Haber T., Lewczuk, J., 1995b. Wybrane wyroby cukiernicze z dodatkiem nasion amarantusa. Żywność Technologia Jakość, 2: 121.

Chrzanowska-Drożdż B., Kaczmarek K., 2007. Yielding of winter barley cultivars. Fragmenta Agronomica, 24(3): 34-40. [in Polish + summary in English]

Das S., 2016. Amaranthus: a promising crop of future. Springer, Singapore

Dmitrieva O., Ivanov S., 2020. Comparative study of amaranth species (*Amaranthus* spp.) in the temperate continental climate of Russian Federation. Acta agriculturae Slovenica, 115.1: 15-24, http://dx.doi.org/10.14720/aas.2020.115.1.1281.

Dziwulska-Hunek A., Kornarzyński K., 2009. Germination of amaranth seeds cv. Aztek and Rawa at various temperatures. Acta Scientiarum Polonorum Technica Agraria, 8(1-2): 3-10. [in Polish + summary in English]

Faruga A., Mikulski D., 1998. Wykorzystanie nasion szarłatu (*Amaranthus cruentus* L.) w żywieniu kurcząt brojlerów i kur niosek. Przegląd Hodowlany, 36: 287-295. [in Polish]

Gajewska R., Lebiedzińska A., Malinowska E., Szefer P., 2002. The health aspects of amaranth. Roczniki Państwowego Zakładu Higieny, 53: 141-147. [in Polish + summary in English]

Gajewski M., Radzanowska J., Jeznach M., Jariene E., Danilcenko H., 2015. Sensory quality evaluation of extruded corn snacks supplemented with pumpkin, Jerusalem artichoke and amaranthus flours, using profile analysis and consumers' test. Postępy Techniki Przetwórstwa Spożywczego, 2 :15-21. [in Polish + summary in English]

Gálová Z., Rajnincová D., Chňapek M., Balážová Ž., Špaleková A., Vivodík M., Hricová A., 2019. Characteristics of cereals, pseudocereals and legumes for their coeliac active polypeptides. Journal of Microbiology, Biotechnology and Food Sciences, 9: 390-395.

Górski T., Kozyra J., 2011. Agroclimatic normals of mean air temperature in Poland over the years 2011–2020. Polish Journal of Agronomy, 5: 21-28, doi: 10.26114/pja.iung.065.2011.05.03.

Jakubowska M., Gardzielewska J., Tarasewicz Z., Szczerbińska D., Karamucki T., Rybak K., Poławska E., Garczewska J., 2013. The effect of amaranth seed added to the standard diet upon selected meat quality traits in the quail. Animal Science Papers and Reports, 31(4): 355-362.

Jakuszew M., 1997. Chemical composition and biological activity of amaranth (*Amaranthus cruentus* L.) seed saponins. Praca doktorska wykonana w Zakładzie Biochemii i Jakości Plonów IUNG (PhD thesis), Puławy. [in Polish + summary in English]

Jamalluddin N., Massawe F.J., Symonds R.C., 2019. Transpiration efficiency of Amaranth (*Amaranthus* sp.) in response to drought stress. The Journal of Horticultural Science and Biotechnology, 94(4): 448-459.

Jendrzejczak E., Śmigerska K., 2014. Impact of presowing soaking of amaranth seeds in solutions of growth regulators. Part I. Effect of some growth regulators on seed germination capacity. Acta Scientiarum Polonorum Agricultura, 13(4): 43-52. [in Polish + summary in English].

Kachiguma N.A., Mwase W., Maliro M., Damaliphetsa A., 2015. Chemical and mineral composition of amaranth (*Amaranthus* L.) species collected from central Malawi. Journal of Food Research, 4(4): 92-102, doi:10.5539/jfr.v4n4p92.

Kaźmierczak A., Bolesławska Z., Przysławski J., 2011. Amaranth – its use in the prevention and treatment of certain civilization-related diseases. Nowiny Lekarskie, 80(3): 192-198. [in Polish + summary in English]

Klebaniuk R., Kowalczuk-Vasilev E., Kiczorowska B., Grela E.R., Winiarska-Mieczan A., Samolińska W., Kwiecień M., Kwiatkowska K., Rusinek-Prystupa E., Jarzyna P., 2018. Nutritious value of selected food products with amaranth addition. Problemy Higieny i Epidemiologii, 99(1): 82-87. [in Polish + summary in English]

Kopeć B., 2013. Thermal conditions in Poland and the possibility of cultivating thermophilic plants. Praca doktorska (PhD thesis), Katedra Ekologii, Klimatologii i Ochrony Powietrza, Uniwersytet Rolniczy im. H. Kołłątaja w Krakowie. [in Polish + summary in English]

Kozak M., Malarz W., Kotecki A., Serafin-Andrzejewska M., 2011. Influence of differentiated nitrogen fertilization on the development, yielding and chemical composition of cultivated amaranth seeds. Zeszyty Naukowe Uniwersytetu Przyrodniczego we Wrocławiu. Rolnictwo, 98(581): 79-94. [in Polish + summary in English]

Króliczewska B., Zawadzki W., Bartkowiak A., Skiba T., 2008. The level of selected blood indicators of laying hens fed with addition of amaranth grain. Electronic Journal of Polish Agricultural Universities, 11(2): http://www.ejpau.media.pl/volume11/issue2/art-18.html.

Longato E., Meineri G., Peiretti P.G., 2017. The effect of *Amaranthus caudatus* supplementation to diets containing linseed oil on oxidative status, blood serum metabolites, growth performance and meat quality characteristics in broilers. Animal Science Papers and Reports, 35(1): 71-86.

Mynbayeva Z., Dryuk O.V., 2020. Amino acid composition of some plants growing in the conditions of Northern Kazakhstan. International Journal of Biology and Chemistry, 13(1): 182-186.

Moszak M., Zawada A., Grzymisławski M., 2018. Właściwości oraz zastosowanie oleju rzepakowego i oleju z amarantusa w leczeniu zaburzeń metabolicznych związanych z otyłością. Forum Zaburzeń Metabolicznych, 9: 53-64.

Mueller-Bieniek A., Walanus A., Zaitz E., 2015. Cultivated plants in medieval Kraków (Poland), with special reference to amaranth (*Amaranthus lividus* L. cf. var *lividus*) and ruderal communities. Acta Palaeobotanica, 55(1): 98-115.

Nalborczyk E., 1995. Amaranthus roślina uprawna ponownie odkryta. Przegląd Piekarsko-Cukierniczy, 6: 34-35.

Nasir S., Allai F.M., Gani M., Ganaie S., Gul K., Jabeen A., Majeed D., 2020. Physical, textural, rheological, and sensory characteristics of amaranth-based wheat flour bread. International Journal of Food Science, doi: 10.1155/2020/8874872.

Niro S., D'Agostino A., Fratianni A., Cinquanta L., Panfili G., 2019. Gluten-free alternative grains: Nutritional evaluation and bioactive compounds. Foods, 8(6): 208, doi: 10.3390/foods8060208.

Noworolnik K., 2009. Effect of some soil properties on yielding of winter triticale and winter rye. Acta Agrophysica, 14(1): 155-166. [in Polish + summary in English]

Noworolnik K., Leszczyńska D., 2018. The comparison of response of spring barley cultivars to sowing date. Polish Journal of Agronomy, 32: 17-22, doi: 10.26114/pja.iung.349.2018.32.02. [in Polish + summary in English]

Ogrodowska D., Zadernowski R., Tańska M., Czaplicki S., 2011. Physical properties of *Amaranthus cruentus* seeds from different cultivation regions in Poland. Żywność Nauka Technologia Jakość, 18(6): 91-104.

Oleksy A., Szmigiel A., Kolodziejczyk M., 2008. Effect of cultivation intensity on protein concentrations and its yield of the winter wheat cultivars. Acta Scientiarum Polonorum Agricultura, 7(1): 47-56. [in Polish + summary in English]

Pedersen B., Knudsen K.B., Eggum B.O., 1990. The nutritive value of amaranth grain (*Amaranthus caudatus*). Plant Foods for Human Nutrition, 40(1): 61-71.

Piłat B., Ogrodowska D., Zadernowski R., 2016. Nutrient content of puffed proso millet (*Panicum miliaceum* L.) and amaranth (*Amaranthus cruentus* L.) grains. Czech Journal of Food Science, 34: 362-369.

Podkówka L., Podkówka Z., Piwczyński D., Buko M., 2015. Effect of cultivar earliness on chemical composition and digestibility of maize grain. Roczniki Naukowe Zootechniki, 42(2): 155-169. [in Polish + summary in English]

Popiela E., Króliczewska B., Zawadzki W., Opaliński S., Skiba T., 2013. Effect of extruded amaranth grains on performance, egg traits, fatty acids composition, and selected blood characteristics of laying hens. Livestock Science, 155(2-3): 308-315.

Punita A., Chaturvedi A., 2000. Effect of feeding crude red palm oil (*Elaeis guineensis*) and grain amaranth (*Amaranthus paniculatus*) to hens on total lipids, cholesterol, PUFA levels and acceptability of eggs. Plant Foods for Human Nutrition, 55(2): 147-157.

Qureshi A.A., Lehmann J.W., Peterson D.M., 1996. Amaranth and its oil inhibit cholesterol biosynthesis in 6-week-old female chickens. The Journal of Nutrition, 126(8): 1972-1978.

Ratusz K., Wirkowska M., 2006. Characterization of seeds and lipids of amaranthus. Rośliny Oleiste/Oilseed Crops, 27(2): 243-250. [in Polish + summary in English]

Reklewska B., Nałęcz-Tarwacka T., Niemiec J., Kraszewska A., 1995. Yolk triacyloglycerol composition and egg quality following the diet containing amaranth meal. Animal Science Papers Report, 13: 73-80.

Sady M., Domagala J., Grega T., Kalicka D., 2007. Effect of the storing period on micro-flora in yoghurts containing amaranth seeds and oat grains added. Żywność Nauka Technologia Jakość, 14(6): 242-250. [in Polish + summary in English].

Salinas I., Pro A., Salinas Y., Sosa E., Becerril C.M., Cuca M., Cervantes M., Gallegos J., 2006. Compositional variation amongst sorghum hybrids: Effect of kafirin concentration on metabolizable energy. Journal of Cereal Science, 44: 342-346.

Skwaryło-Bednarz B., 2008. Evaluation of biological properties of soil under cultivation of amaranth (*Amaranthus cruentus* L.). Acta Agrophysica, 12(2): 527-534. [in Polish + summary in English]

Skwaryło-Bednarz B., Jamiołkowska A., Kopacki M., Krzepiłko A., Jarosz K., 2018. Amaranth and valuable chemical composition of its seeds. Aura, 11: 6-9. [in Polish + summary in English]

Sosnowska B., Achremowicz B., 2000. Trials in the use the *Amaranthus* flour for biscuits baking. Żywność Nauka Technologia Jakość, 4(07): 48-53. [in Polish + summary in English]

Srichuwong S., Curti D., Austin S., King R., Lamothe L., Gloria-Hernandez H., 2017. Physicochemical properties and starch digestibility of whole grain sorghums, millet, quinoa and amaranth flours, as affected by starch and non-starch constituents. Food Chemistry, 233: 1-10.

Srivastava S., Sreerama Y.N., Dharmaraj U., 2021. Effect of processing on squalene content of grain amaranth fractions. Journal of Cereal Science, 100, 103218.

Stetter M.G., Schmid K.J., 2017. Analysis of phylogenetic relationships and genome size evolution of the *Amaranthus* genus using GBS indicates the ancestors of an ancient crop. Molecular Phylogenetic Evolution, 109: 80-92.

Stetter M.G., Zeitler L., Steinhaus A., Kroener K., Biljecki M., Schmid K.J., 2016. Crossing methods and cultivation conditions for rapid production of segregating populations in three grain amaranth species. Frontiers in Plant Science, 7:816, doi: 10.3389/fpls.2016.00816.

Sułkowski M., Gawlik-Dziki U., Czyż J., 2011. Quinoa – a poorly known pseudocrop with cosmic properties. Kosmos, 60(3-4): 475-481. [in Polish + summary in English]

Suresh S., Chung J.W., Cho G.T., Sung J.S., Park J.H., Gwag J.G., Baek H.J., 2014. Analysis of molecular genetic diversity and population structure in *Amaranthus* germplasm using SSR markers. Plant Biosystems - An International Journal Dealing with all Aspects of Plant Biology, 148: 635-644, doi: 10.1080/11263504.2013.788095.

Tillman P.B., Waldroup P.W., 1987. Effects of feeding extruded grain amaranth to laying hens. Poultry Science, 66(10): 1697-1701.

Worobiej E., Piecyk M., Rębiś M., Rębiś Ż., 2009. The content of non-nutrient bioactive compounds and antioxidant proprieties of amaranth products. Bromatologia i Chemia Toksykologiczna, 42(2): 154-157. [in Polish + summary in English]

Woźniak A., Makarski B., 2013. Content of minerals, total protein and wet gluten in grain of spring wheat depending on cropping systems. Journal of Elementology, 18(2): 297-305, doi: 10.5601/jelem.2013.18.2.09.

Ziernicka-Wojtaszek A., 2015. Climatic water balance in Poland in the light of the present day climate change. Woda-Środowisko-Obszary Wiejskie, 15(4): 93-100. [in Polish + summary in English]

Zralý Z., Písaříková B., Hudcova H., Trčková M., Herzig I., 2004. Effect of feeding amaranth on growth efficiency and health of market pigs. Acta Veterinaria Brno, 73: 437-444.

Author	ORCID
Marcin Różewicz	0000-0002-3281-5533

received – 9 April 2021
revised – 10 September 2021
accepted – 22 November 2021