Acta Sci. Pol. Hortorum Cultus, 19(6) 2020, 153–164

https://czasopisma.up.lublin.pl/index.php/asphc ISSN 1644-0692 e-ISSN 2545-1405 DOI: 10.24326/asphc.2020.6.13

REVIEW

Accepted: 8.10.2020

AMARANTH SEEDS AS A SOURCE OF NUTRIENTS AND BIOACTIVE SUBSTANCES IN HUMAN DIET

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ABSTRACT

Amaranth is one of the oldest arable crop in the world. It was brought to Europe around the 17th century, but as an ornamental plant. It was not until the 1970s, after thorough examination of the chemical composition of amaranth seeds, in effect of which the nutritional value of this plant was rediscovered and recognized. Since then, there has been increased interest in amaranth as a 'plant with a future'. A great deal of scientific research has been carried out, leading to recognition of its nutritional, ecological, agricultural and health-promoting values (especially for the prevention and treatment of diseases of the cardiovascular, nervous and digestive systems). Among cultivated amaranths species *Amaranthus caudatus*, *Amaranthus cruentus* and *Amaranthus hypochondriacus* have the highest nutritional value. However, differences in the nutrient content are also noticeable between these species. One of the attributes of this plant is the high content of highly digestible complete protein and the presence of all essential amino acids in the seeds. The seeds also contain large amounts of gluten-free starch with a small grain diameter, fibre, vitamins and minerals. Furthermore, they have a high fat content compared to cereal grains. Amaranth oil consists mainly of unsaturated fatty acids (oleic, linoleic and linolenic). Some of the unsaturated fatty acids, such as linolenic acid, are exogenous fatty acids, essential for the human body. Valuable components of the fatty acid fraction include squalene, tocopherols and tocotrienols. These compounds are particularly valuable due to their antioxidant properties.

Key words: amaranth, chemical composition, nutritional value

INTRODUCTION

Amaranth is one of the oldest arable crop in the world [Skwaryło-Bednarz 2012]. The origin of the name amaranth is different: the Sanskrit word for the plant 'amaranth' means 'King of Immortality' and the Greek word 'amaranthus' means 'never withering' [Wołosik et al. 2013]. The nutritional value of this plant was recognized 4000 years ago by the Incas, Mayans and Aztecs [Skwaryło-Bednarz and Nalborczyk 2006]. The ancestors of the Yaqui Indians from Sonora used amaranth seeds for religious purposes. They sacrificed them to the gods of war and rain. Amaranth was brought to Europe in the late 16th and early 17th centuries [Nalborczyk 1995].

Renewed interest in amaranth use began in the 1970s. Since that time, many scientific studies have shown that it is an extremely valuable plant for people, due to its nutritional, medicinal, ecological and agricultural attributes [Joshi and Rana 1991, Espitia 1992,

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Nalborczyk 1995, 1999, Piesiewicz and Ambroziak 1995, Kłoczko 2008, Ferreira and Areas 2010, Rosa et al. 2012]. Its purported health benefits include reduced plasma cholesterol, stimulation of the immune system, anticancer activity, reduced blood glucose levels, a positive effect on hypertension and anaemia, and anti-allergic and antioxidant activity [Caselato-Sousa and Amaya-Farfán 2012].

The aim of the study was to characterize and assess the chemical composition of the seeds of amaranth grown for seed in the context of their use in the human diet. The research was based on the most important Polish and world literature reports [Becker et al. 1981, Lehmann et al. 1994, Gontarczyk 1996, Dodok et al. 1997, Jahaniaval et al. 2000, Bruni et al. 2002, Písaříková et al. 2005, Rutkowska 2006, Januszewska-Jóźwiak and Synowiecki 2008, Barba de la Rosa et al. 2009, Alvarez-Jubete et al. 2010, Grobelnik-Mlakar et al. 2010, Sujak and Dziewulska-Hunek 2010, Caselato-Sousa and Amaya-Farfán 2012, Skwaryło-Bednarz 2012, Kubelková et al. 2013, Palombini et al. 2013, Venskutonis and Kraujalis 2013, Amare et al. 2015, Bhat et al. 2015, Kachiguma et al. 2015, USDA 2019, Wołosik and Markowska 2019].

BOTANICAL CHARACTERISTICS OF AMARANTH

Amaranthus belongs to the class *Dicotyledones*, the family *Amaranthaceae*, and the genus *Amaranthus* [Eshete et al. 2016]. The amaranth genus includes about 70 species of herbaceous plants, which have been divided into four groups: seed, vegetable, ornamental and weed amaranth [Suresh et al. 2014]. Species grown for seed include *Amaranthus cruentus*, *Amaranthus caudatus*, *Amaranthus hypochondriacus* as well as their wild parent species – *Amaranthus hybridus* L., *Amaranthus quitensis* Willd. ex Spreng. and

Fig. 1. *Amaranthus cruentus* L. ‘Rawa’ (phot. B. Skwaryło-Bednarz)

Amaranthus powellii S. Wats. [Costea et al. 2004]. Vegetable forms include *Amaranthus dubius*, *Amaranthus lividus* and *Amaranthus tricolor* [Stallknecht and Schulz-Schaeffer 1993].

Great diversity of morphology and colour is observed among amaranth species. Most are annuals, but some, such as *Amaranthus muricatus* or *Amaranthus deflexus*, are perennials [Rutkowska 2006, Skwaryło-Bednarz and Nalborczyk 2006].

The height of individual species ranges from 0.3 to over 3 m. The most important species economically include the following [Rutkowska 2006, Espitia et al. 2010]:

– Edulis and South American (morphological group of *Amaranthus caudatus*),

– Mixteco, Aztec, Mercado, Nepal and Picos (morphological groups of *Amaranthus hypochondriacus*),

– Sandorache (morphological group of *Amaranthus hybridus*),

– wild forms and some cultivated forms of *Amaranthus cruentus* (Mexican, Guatemalan and African) and *Amaranthus tricolor*.

The genus of *Amaranthus* is characterized by a large variety of colors of individual organs. The stems and leaves may be green, red, purple or multi-coloured [Skwaryło-Bednarz and Nalborczyk 2006]. Inflorescence colours vary from gold to green, pink, red, purple and brown. The seeds may be white, gold, cream-coloured, marbled, brown or black. The colour diversity of the vegetative and reproductive parts of these plants can be observed even within a single morphological group. Most of the wild, vegetable and fodder forms have dark seeds, while light seeds are characteristic of amaranth grown for seed [Wołosik and Markowska 2019].

Six amaranth species grow in the natural conditions of Poland, the most common of which is *Amaranthus retroflexus* L., which is a noxious weed, especially in root crops [Gontarczyk 1996]. Ornamental species of this plant are grown in Poland as well. They are a unique decorative element in gardens and squares. Increasingly, they are also used as an element of floral arrangements and bouquets [Nalborczyk 1995].

Species used as pseudo-cereals are the most important plants of the genus *Amaranthus*. These are *Amaranthus hypochondriacus*, *Amaranthus caudatus*, and in Poland especially *Amaranthus cruentus* [Bhat et al. 2015]. The current register of original cultivars in Poland includes two cultivars of amaranth grown for seed. These are 'Rawa' (*Amaranthus cruentus* L.) and 'Aztek' (*Amaranthus hypochondriacus* × *Amaranthus hybridus* L.) [Skwaryło-Bednarz 2008]. Plants of the 'Rawa' cultivar have stiff green stems, long, ovate, light green leaves, short, upright, yellow-green inflorescences, and cream-coloured seeds (Fig. 1). Plants of the 'Aztek' cultivar are slightly shorter than the 'Rawa' cultivar and mature earlier (Fig. 2). Their inflorescences are long and maroon, with cream-coloured seeds [Nalborczyk 1995].

Fig. 2. *Amaranthus hypochondriacus* × *Amaranthus hybridus* L. 'Aztek' (phot. Barbara Skwaryło-Bednarz)

CHEMICAL COMPOSITION OF AMARANTH SEEDS

Protein. Among cultivated amaranths species *Amaranthus caudatus*, *Amaranthus cruentus* and *Amaranthus hypochondriacus* have the highest nutritional value (Tab. 1). The average protein content in the seeds of *Amaranthus* spp. is 13.6% [Caselato-Sousa and Amaya-Farfán 2012, USDA 2016], with the maximum content reaching even 19.0% [Gamel et al. 2006]. Amaranth seeds contain more protein than wheat, maize rice or sorghum [Kanensi et al. 2011]. The most protein has been noted in the seeds of *Amaranthus caudatus*, and the least in the species most often cultivated in Poland, *Amaranthus cruentus* (Tab. 1). It is a complete protein with very high bioavailability and biological value. The true digestibility of amaranth protein varies from 79 to 87%, and the *in vitro* digestibility from 61 to 70% [Grajeta 1997]. The major protein fractions include albumins and globulins as well as low amounts of glutenins, gliadins and prolamins [Bressani and Garcia 1990, Kaźmierczak et al. 2011].

The main advantages of amaranth include not only its high protein content, but also its amino acid composition [Alvarez-Jubetea et al. 2010, Biel and Jaskowska 2010, Piecyk et al. 2009, Montoya-Rodríguez et al. 2015] (Tab. 2). The percentage of all essential amino acids, excluding tryptophan, was 43–49%, which is higher than the WHO reference standard (31%) [Amare et al. 2015]. Amaranth protein has been found to have a complementary amino acid profile with respect to traditional cereal proteins [Venskutonis and Kraujalis 2013]. Its seeds have all the amino acids that the human body does not produce [Caselato-Sousa and Amaya-Farfán 2012]. They have particularly high lysine content [Amare et al. 2015] (Tab. 2), which is important for the development of children and adolescents. The total content of lysine in the seeds of various amaranth species, including those grown in Ethiopia, is higher than in the case of commonly available cereals, but similar to that of legumes [Amare et al. 2015]. In addition to the high lysine content in the protein of amaranth seeds, there are also large amounts of sulphur-containing amino acids – methionine and cysteine [Grobelnik-Mlakar et al. 2010, Palombini et al. 2013, Wołosik and Markowska 2019]. Their content in amaranth seeds is higher than in the protein of legumes [Amare et al. 2015].

An amino acid that limits the use of amaranth is leucine [Wolska et al. 2011]. However, it occurs in smaller quantities in amaranth than in cereals such as barley or corn. This is why food products made from blends of amaranth flour with flour from traditional cereal plants have the highest nutritional value.

Fat. The grain of amaranth species grown for seed has higher lipid content than that of traditional cereal plants (Tab. 1). It is more than three times higher than in the grain of wheat, rye or rice and over 1.5 times higher than in maize (Tab. 1). The seeds contain from 5.6% to even 10.9% crude fat [Bhat et al. 2015, Mlakar et al. 2009]. The most crude fat has been noted in the seeds of *Amaranthus hypochondriacus*, while the least in *Amaranthus cruentus* (Tab. 1). Crude fat content depends not only on the species, but also weather conditions and macroelement fertilization [Skwaryło-Bednarz 2012].

Fatty acids. Not only the quantity, but also the composition of the lipids of amaranth grain is favourable [Jahanival et al. 2000, Prokopowicz 2001, Ratusz and Wirkowska 2006] (Tabs. 1, 3). The composition of the oil is dominated by unsaturated fatty acids such as oleic acid, linoleic acid, and linolenic acid (Tab. 3). This small amount of linolenic acid provides stability against autoxidation, which causes oil to become rancid when it is exposed to oxygen [Ratusz and Wirkowska 2006]. Some unsaturated fatty acids, such as linolenic acid, are exogenous acids essential for the human body, playing an important role in hormone synthesis, cell membrane structure, and regulation of their permeability [Januszewska-Jóźwiak and Synowiecki 2008]. Hence the potential use of amaranth seeds in medicine to alleviate atherosclerotic disorders. Saturated fatty acids are present in small quantities, mainly in the form of palmitic and stearic acids. Various scientific studies show that the ratio of saturated to unsaturated fatty acids ranges from 0.29 to 0.43 [Gontarczyk 1996, Grobelnik-Mlakar et al. 2010] or from 0.26 to 0.32 [He et al. 2002].

Squalene. Amaranth oil contains large amounts of squalene (3.2–8.0%), much more than olive oil (0.7–1.0%) [Berganza et al. 2003, Januszewska-Jóźwiak and Synowiecki 2008]. It should be noted that the total squalene content is dependent primarily on the method of oil extraction (especially extraction the oil with supercritical CO_2 gives the greatest amount of squalene) [Nasirpour-Tabrizi et al. 2020]. It is often used in the production of cosmetics and medicines [Plate and Areas 2002], as well as analgesic and anti-inflammatory ointments [Januszewska-Jóźwiak and Synowiecki

Table 1. Comparison of the chemical composition of the seeds of various species of amaranth and selected cereals (% DW)

Species	Protein	Crude fat	Carbohydrates	Fibre	Crude ash	Moisture	Source
Amaranthus spp.	13.6	7.0	65.3	6.7	2.9	11.3	USDA 2019, Caselato-Sousa and Amaya-Farfán 2012
	15.8–16.9	n.d.	n.d.	n.d.	n.d.	n.d.	Písaříková et al. 2005
Amaranthus cruentus	15.7	7.2	62.0	4.2	3.3	7.5	Rutkowska 2006
Amaranthus caudatus	17.6–18.4	6.9–8.1	56.0–62.0	3.2–5.8	3.1–4.4	9.5–11.6	Rutkowska 2006
	14.6	4.7	40.5	n.d.	2.6	7.2	Burgos and Armada 2015
Amaranthus hypochondriacus	n.d.	7.9–8.9	n.d.	n.d.	n.d.	n.d.	Barba de la Rosa et al. 2009
	17.9	7.7	58.0	2.2	4.1	11.1	Rutkowska 2006
Common wheat	12.0	1.9	68.0	1.8	1.9	14.5	Rutkowska 2006
Rye	9.0	1.9	71.0	1.9	1.7	14.5	
Maize	10.3	4.5	67.7	2.3	1.4	13.8	
Rice	8.5	2.1	75.4	0.9	1.4	11.7	

n.d. – not determined

Table 2. Comparison of the content of selected amino acids in the seeds of amaranth and other cereals (mg·100 g^{-1} protein)

Seeds	Trp	Met/Cys	Thr	Ile	Val	Lys	Phe/Tyr	Leu	Source
Amaranthus cruentus	0.90	4.60	3.90	4.00	4.40	6.00	7.90	6.20	Becker et al. 1981
	n.d.	4.00	3.40	3.60	4.20	5.10	6.00	5.10	Saunders and Becker 1984
Amaranthus caudatus	1.10	4.90	4.00	4.10	4.70	5.90	8.10	6.30	Becker et al. 1981
	n.d.	4.70	2.80	3.60	4.10	5.30	6.20	5.30	Saunders and Becker 1984
Amaranthus hypochondriacus	1.82	0.60 (Met)	3.30	2.70	3.90	5.95	8.42	4.20	Dodok et al. 1997
	n.d.	4.70	3.30	3.90	4.50	5.50	7.30	5.70	Saunders and Becker 1984
Common wheat	1.20	3.50	2.70	4.10	4.30	2.60	8.10	6.30	Grobelnik-Mlakar et al. 2010
Barley	1.20	3.20	3.20	4.00	4.70	3.20	8.20	6.50	
Maize	0.60	3.20	4.00	4.60	5.10	1.90	10.60	13.00	
Rice	1.00	3.00	3.70	4.50	6.70	3.80	9.10	8.20	
Oat	1.20	3.40	3.10	4.80	5.60	3.40	8.40	7.00	

Trp – tryptophan, Met/Cys – methionine/cysteine, Thr – threonine, Ile – isoleucine, Val – valine, Lys – lysine, Phe/Tyr – phenylalanine/tyrosine, Leu – leucine, n.d. – not determined

2008]. Squalene displays health-promoting properties [Bodroža-Solarov et al. 2007] through its antioxidant capacity [Yokota 1997, Briganti and Picardo 2003]. It participates primarily in the elimination of free radicals. In animal studies, squalene has been found to reduce the risk of myocardial infarction induced by isoproterenol. It is likely that squalene inhibits lipid peroxidation [Sabeena-Farvin et al. 2004, Wołosik and Markowska 2019].

Tocopherols and other antioxidant compounds. Other substances contained in amaranth oil include tocopherols – α-, β-, γ- and δ-tocopherol [Skwaryło-Bednarz 2010, 2012, Arendt and Zannini 2013] (Tab. 4), tocotrienols (α-, β-, γ- and δ-), and phytosterols [Prokopowicz 2001, Rutkowska 2006, Skwaryło-Bednarz and Krzepiłko 2008]. Tocopherols display good antioxidant activity and are being studied as potential hypocholesterolaemic agents [Escudero et al. 2006]. In particular, methanolic extract of the grain has been shown to exhibit high antioxidant potential [Bhat et al. 2015]. Tocotrienols have the ability to inhibit HMG-CoA reductase activity [Paśko and Bednarczyk 2007]. In laboratory animals tocotrienols have been shown to inhibit cholesterol synthesis, mainly that of "bad" LDL cholesterol [Putnam 1991, Wołosik and Markowska 2019].

Rutkowska [2006] reports that amaranth oil contains δ-7-stigmasterol (15–18%), δ-7-ergosterol

Table 3. Content of fatty acids in amaranth seeds (%)

Fatty acid	*Amaranthus* spp.			*Amaranthus cruentus*	*Amaranthus hypochondriacus*
Lauric, C12:0	n.d.	n.d.	n.d.	0.49	n.d.
Myristic, C14:0	n.d.	0.20	n.d.	0.24	0.21–0.29
Palmitic, C16:0	12.00–25.00	20.40	20.90	17.02	21.40–23.80
Palmitoleic, C16:1	n.d.	n.d.	n.d.	0.09	0.10–0.19
Stearic, C18:0	2.00–8.60	3.90	4.10	2.12	3.11–3.98
Oleic, C18:1	19.00–35.00	22.30	23.70	19.13	22.80–31.50
Linoleic, C18:2	25.00–62.00	48.00	47.80	24.84	39.40–49.10
Linolenic, C18:3	0.30–2.20	1.50	0.90	1.29	0.65–0.93
Saturated	24.00	26.70	26.90	19.87	26.80–28.60
Monounsaturated	76.00	23.80	23.90	19.22	23.10–23.90
Polyunsaturated	0.00	49.50	49.10	26.33	47.00–50.00
Source	Gontarczyk 1996	Kubelková et al. 2013	Alvarez-Jubete et al. 2010	Sujak and Dziewulska-Hunek 2010	Jahaniaval et al. 2000

n.d. – not determined

Table 4. Content of tocopherol homologues in amaranth seeds ($mg \cdot kg^{-1}$)

Tocopherols	*Amaranthus cruentus*	*Amaranthus caudatus*	*Amaranthus cruentus* and *Amaranthus hypochondriacus*
α-tocopherol	10.20–20.60	12.50–34.81	2.97–15.65
β-tocopherol	35.40–48.50	19.55–43.86	5.92–11.47
γ-tocopherol	2.00–4.00	0.60–2.20	0.95–8.69
δ-tocopherol	15.50–18.40	21.70–48.79	0.01–0.42
Source	Skwaryło-Bednarz 2012	Bruni et al. 2002	Lehmann et al. 1994

(12–15%), stigmasterol (10–13%), and the little-known and atypical spinasterol (46–54% of the total amount of sterols). It should be emphasized that phytosterols are antimutagenic and anti-carcinogenic [Kłoczko 2008]. Moreover, they participate in the synthesis of vitamins (vitamin D) and hormones. One of the phytosterols, spinasterol, increases the excretion of cholesterol, thereby reducing its level in the blood [Kaźmierczak et al. 2011, Piesiewicz 2009].

Carbohydrates. The carbohydrate content in the seeds of the analysed amaranth species is very similar to that found in wheat and maize (Tab. 1). Total fibre content ranges from 7.6 to 19.6% [Arendt and Zannini 2013], and raw fibre content in the most commonly cultivated amaranth species ranges from 2.2 to 6.7% DW [Rutkowska 2006, Grobelnik-Mlakar et al. 2010, Caselato-Sousa and Amaya-Farfán 2012, USDA 2019] (Tab. 1). The amount of fibre expressed as dietary fibre is 3.1–5.0% [Grobelnik-Mlakar et al. 2010]. In *Amaranthus cruentus* seeds, the soluble fraction of the fibre constitutes 14%, in *Amaranthus hypochondriacus* 25%, and in *Amaranthus caudatus* 33–44% in light seeds and 18% in dark seeds [Pedersen et al. 1990]. The fibre of *Amaranthus caudatus* seeds includes lignin, uronic acid and biopolymers made up of glucose, arabinose, xylose, mannose and galactose molecules. Lignins constitute about 30% of the total fibre in light seeds and about 50% in dark seeds [Grajeta 1997].

Amaranth seeds contain gluten-free starch [Valcárcel-Yamani and Silva Lannes 2012] and a small amount of gluten. Depending on the species, the content of gluten-free starch ranges from 48 to 69% [Rutkowska 2006]. The grains of amaranth starch are very small (1.0–3.0 μm) and several times smaller compared to grains of other cereals [Grobelnik-Mlakar et al. 2010, Valcárcel-Yamani and Silva Lannes 2012]. Starch in amaranth seeds occurs mainly in the form of amylopectin. Amylose content ranges from 0 to 22%. Nutrition experiments have shown that amaranth starch is 2–4 times more easily digested and assimilated than millet starch.

Other sugars determined in amaranth seeds are sucrose (0.4–2.0%), raffinose (0.27–12.39%), stachyose (0.02–0.29%), maltose (0.02–0.36%), glucose, fructose and other monosaccharides (0.05–0.67%) and inositol (about 1%) [Rutkowska 2006, Venskutonis and Kraujalis 2013, Wołosik and Markowska 2019].

Minerals. Amaranth grain is also a valuable source of important minerals, such as potassium, calcium, magnesium, zinc, iron, magnese and selenium [Czerwiński et al. 2004]. However, their quantity can vary significantly depending on the species (Tab. 5). The content of calcium, potassium and magnesium are much high-

Table 5. The content of selected minerals in amaranth seeds (mg·100 g^{-1} DW)

Species	K	Na	Ca	Mg	Zn	Fe	Mn	Source
Amaranthus spp.	236.00–455.20	n.d.	78.30–1004.60	44.31–97.38	0.53–1.20	3.61–22.51	n.d.	Kachiguma et al. 2015
	n.d.	16.00–48.00	130.00–285.00	230.00–336.00	36.20–40.00	7.20–17.40	n.d.	Grobelnik--Mlakar et al. 2010
	508.00	n.d.	159.00	248.00	2.90	7.60	3.30	Caselato-Sousa and Amaya--Farfán 2012
	508.00	4.00	159.00	3.33	2.87	7.61	3.33	Soriano-García et al. 2018
Amaranthus cruentus	770.20	4.10	283.10	425.20	n.d.	29.40	4.10	Palombini et al. 2013
	337.00	6.30	223.00	218.00	n.d.	8.30	n.d.	Rutkowska 2006
Amaranthus hypochondriacus	n.d.	n.d.	51.93	84.80	2.89	6.54	0.88	Bhat et al. 2015

n.d. – not determined

Table 6. Content of selected vitamins in amaranth grain (mg·100 g^{-1})

Vitamins	*Amaranthus* spp.		*Amaranthus cruentus*	
B_1, thiamine	0.11	0.07–0.10	0.12	0.16
B_2, riboflavin	0.20	0.19–0.23	0.20	0.41
B_6, pyridoxine	0.59	0.52–0.60	n.d.	n.d.
B_3, niacin	0.92	1.00–1.45	0.92	2.5
B_7, biotin	n.d.	42.50	n.d.	n.d.
B_9, folic acid	0.82	0.44	0.82	0.96
C, ascorbic acid	4.20	4.50–4.90	4.20	n.d.
Source	Caselato-Sousa and Amaya-Farfán 2012	Rutkowska 2006	Soriano-García et al. 2018	Venskutonis and Kraujalis 2013

n.d. – not determined

er than in the grain of traditional cereal plants, and the 1.9 : 2.6 ratio of phosphorus to calcium (P/Ca) is nutritionally very beneficial [Rutkowska 2006].

High iron content has also found in amaranth seeds (3.61–22.51 mg·100 g^{-1}) in comparison to legumes (4.7–8.0 mg·100g^{-1}) and meat and cereals (0.70–3.90 mg·100 g^{-1}) [Rutkowska 2006, Kachiguma et al. 2015] (Tab. 5). The seeds of this plant, especially *Amaranthus cruentus*, provide five times more iron than wheat kernels, and therefore can be a valuable component of diets and nutritional products for people with anaemia or in baby food. However, research by Urosevic et al. [2015] indicates that iron deficiency in growing pigs cannot be corrected by using *Amaranthus cruentus* as an iron supplement. Scientific research confirms that the content of micronutrients such as copper and manganese in seeds of *Amaranthus cruentus* L. is fertilized by macroelements, and the content of zinc is a genetic factor [Skwaryło-Bednarz et al. 2011].

Vitamins. Amaranth seeds contain large amounts of vitamin B_6 (pyridoxine) and vitamin B_9 (folic acid) (Tab. 6). They are also a valuable source of vitamin B_2 (riboflavin) and vitamin B_3 (niacin) [Wołosik and Markowska 2019]. Amaranth flour is also rich in vitamins. It contains riboflavin (0.19–0.23 mg·100 g^{-1} flour), ascorbic acid (4.50 mg·100 g^{-1} flour), niacin (1.17–1.45 mg·100 g^{-1} flour) and thiamine (about 0.07 mg·100 g^{-1}) [Grobelnik-Mlakar et al. 2010].

Crude ash. Crude ash in the seeds of *Amaranthus* spp. constitutes about 2.8% DW [Caselato-Sousa and Amaya-Farfán 2012, USDA 2019], with recorded contents from 4.4 to 8.7% [Kachiguma et al. 2015] (Tab. 1). In the seeds of *Amaranthus cruentus*, the species most often grown in Poland, its content is 3.3%, which is higher than in cultivated cereals [Rutkowska 2006] (Tab. 1).

Antinutrients. Antinutrients are present in amaranth in small amounts and with great variability. Antinutrients that have been detected in the seeds include trypsin and chymotrypsin inhibitors, phytates, and saponins [Grajeta 1997]. Trypsin inhibitors are of particular importance [Januszewska-Jóźwiak and Synowiecki 2008]. Their action results in the secretion of cholecystokinin, which increases the flow of bile to the duodenum. This in turn increases the conversion of cholesterol to bile acids and decreases serum cholesterol [Escudero et al. 2004].

Many heating processes, such as boiling, baking, drying or autoclaving, can significantly reduce the content of antinutrients in seeds [Schnetzler and Breene 1994, Aderibigbe et al. 2020].

CONCLUSIONS

Amaranthus spp. seeds have an especially valuable chemical composition. *Amaranthus caudatus, Amaranthus cruentus* and *Amaranthus hypochondriacus* have the highest nutritional value among the cultivated amaranth species. However, differences in the nutrient content are also noticeable between these species. They contain large amounts of protein with a better and at the same time complementary amino acid profile in relation to cereals, and fat with a large proportion of unsaturated fatty acids. Squalene, tocopherols, and tocotrienols with antioxidant properties are present in amaranth seed oil. The seeds also contain gluten-free starch and numerous vitamins and minerals, and therefore can be used in diets for people with celiac disease or anaemia and in baby food. Clinical trials confirm the value of amaranth seeds in the diet, due to their content of bioactive components. They can be both a valuable component of functional food and a supplement to a normal, daily diet. Products made from amaranth can be used in a variety of diets: prophylactic, particularly to reduce the risk of heart disease and atherosclerosis, anti-ageing (squalene with antioxidant properties), gluten-free, high-protein, for skeletal diseases – high content of calcium and tocotrienols (anti-inflammatory agents) and vegetarian (high content of lysine, iron, calcium and vitamins).

ACKNOWLEDGEMENTS

The authors acknowledge the financial support of University of Life Sciences in Lublin, project DS/OKK/s/44/2020.

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