



UTILIZATION OF AMARANTHUS SPP. GRAINS IN FOOD

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Abstract: Recently there has been a rediscovery of some ancient crops due to increased consumer demands for a healthier diet with medicinal and therapeutic effects. One such crop is a pseudocereal *Amaranthus* sp., which is nutritionally more favourable than many widespread kinds of cereal and meets most of the requirements of modern diets. The incorporation of amaranth species in food formulations would expand the assortment of food products present on the market. The high nutritional quality and potential functionality of amaranth-based food products have been the subject of extensive scientific research. This study aims at reviewing the currently available data on the application of amaranth grains in the food industry and manufacturing and focuses on the functionalities of these products, providing an overview of the current amaranth value chain.

Key words: *amaranth, bakery, pasta, snacks, edible films, malted food*

INTRODUCTION

Amaranth is a pseudocereal crop that has been receiving increased attention among nutritionists and agronomists since the 1980ies due to its unique nutritional quality, nutraceutical profile and agronomic potential. It has been listed in the group of „superfoods“ (Waisundara, 2020), a popular category reserved for natural, nutrient-dense, low-calory and health-beneficial food. Unfortunately, it has not entered the mainstream of industrial food processing.

Amaranthus sp. was a staple crop of Pre-Columbian civilizations but it was abandoned upon the Spanish conquest of America (Kauf-

man, 1992). Nowadays, its cultivation and consumption are present throughout India, Nepal, China, Indonesia, Malaysia; Central America, Mexico; Southern and Eastern Africa (Maurya & Arya, 2018). The genus *Amaranthus* L. includes over 60 species, most of which are cosmopolitan weeds and cultivated amaranth species that can be used for food purposes. (Maurya & Arya, 2018). Amaranth species that are commonly used for grain production are *A. cruentus*, *A. caudatus*, and *A. hypochondriacus* (Aderibigbe et al., 2022).

This crop has an outstanding nutritional composition that includes high protein content, ran-

ging from 12.5% to 17.6% and high oil content, from 6 to 10% (Kaufman, 1992). In contrast to pulse crops, amaranth protein has extraordinarily balanced amino acids and is also relatively rich in sulphur-containing amino acids (Maurya & Arya, 2018; Marquez-Molina & Lopez-Martinez, 2020). The lipid fraction is a rich source of high biologically active compounds, such as squalene up to (8%), tocopherols (2%), phospholipids (10%), and phytosterols (2%) (Alegbejo, 2012). The vitamin content in the grains is limited to the presence of B1, B2 B3 and E. The grains have been reported to be great sources of phosphorous, calcium and iron but also contain zinc, manganese and copper (Schmidt, Veruma-Bernardi, Forti & Mendes Ribeiro Borges, 2021). According to Berghofer and Schoenlechner (2002) amaranth grains contain 0.3-0.6% phytic acid. It also contains phytonutrients with high antioxidative activity, of which the most abundant are ferulic acid, anthocyanins and quercetin (Soriano-García & Aguirre-Díaz, 2020). Owing to a well-balanced nutritional profile and abundance in phytonutrients, it possesses remarkable functional properties linked to numerous health effects. This plant exerts high antioxidant activities, hypocholesterolemic, anti-inflammatory, hepatoprotective, gastroprotective, cardioprotective, antidiabetic, and antitumor effects (Peter & Gandhi, 2017; Maurya & Arya, 2018).

The additional advance of amaranth grain is that it is gluten-free and it can be used by people who suffer from celiac disease which further increases its utilization potential (Barca, Rojas-Martínez, Islas-Rubio & Cabrera-Chávez, 2010). Celiac disease is a disease caused by the intolerance to gluten proteins from cereals like wheat, barley and rye. Its prevalence is up to one per cent in any population over the world (Schuppan, Junker & Barisani, 2009). Incorporation of amaranth in various forms into staple foods like bakery products and cookies could be a successful strategy for the production of highly nutritious and functional foods with health benefits. This could be especially beneficial for specific population groups like people on a conscious diet, coeliac, vegetarian and vegan consumers (Sabbione, Suarez, Añón & Scilingo, 2019).

The main purpose of this article is to provide an overview of food applications of amaranth grain and the functionalities of these products.

TRADITIONAL FOODS

There are many traditional uses of *Amaranthus* grain around the world. Kaufman (1992) emphasized several applications such as Mexican sweets "alegria"; Mexican drink called "atole"; Indian sweets "rajgeera" and Nepal traditional dish made from amaranth grain flour "sattoo".

Alegria is the most famous Mexican candy obtained by mixing popped amaranth with viscous brown molasses syrup or honey (Milan-Carrillo, Montoya-Rodríguez, Gutierrez-Dorado, Perales-Sanchez & Reyes-Moreno, 2012).

Preparation of atole was the following: 500 g of natural amaranth flour is mixed with 6 litres of water at a medium temperature of 90 °C and simmered favouring the evaporation and viscosity of the drink (Gonzalez Acevedo, Hernandez Reyes, Gaytán Dario, Victoria Campos & Palos Lucio, 2018).

Indian name for amaranth is Rajgeera or Ramdana grain. Spurthi, Lakshmi, Lakshmi, Raghavendra and Devi (2021) described four traditional Indian savouries (murukulu, namkpara, khakra and chuduwa) prepared using puffed amaranth grains and flour as major ingredients. Sensory testing of the savouries showed that namakpara made using puffed amaranth flour had high overall acceptability (8.30) followed by chuduwa (8.20), murukulu (7.55) and khakhra (6.60) (Spurthi et al. 2021).

Examination of the perception of Mexican consumers towards amaranth showed that traditional foods obtained from this grain are healthy functional products, but at the same time tasty (Rojas-Rivas, Espinoza-Ortega, Thomé-Ortiz & Moctezuma-Pérez, 2019).

BAKERY GOODS

Bread

The most commonly consumed white (refined) wheat bread is considered to be nutritionally poor. The addition of an ingredient of superior nutritional quality such as amaranth grain could improve the nutritional quality of baked products (Bodroža-Solarov, Filipčev, Kevrešan, Mandić & Šimurina, 2008). Many researchers have dealt with replacing wheat or other cereal flour with amaranth flour. Sanz-Penella, Wronkowska, Soral-Smietana & Haros (2013) investigated the effect of replacing (up to 40%) wheat flour with whole

amaranth flour to evaluate its potential feasibility in baking. Substitution of amaranth flour significantly increased the level of proteins, dietary fibres, lipids, minerals and phytates. As for sensory evaluation, the optimal supplementation level was 20 g/100 g flour basis.

Evaluation of the technological and nutritional quality of bread enriched with amaranth flour limited the supplementation level to a maximum of 25 g/100 g flour basis in a similar investigation by Miranda-Ramos, Sanz-Ponce & Haros (2019). Bread supplementation with whole amaranth flour affected iron bioavailability. A Caco-2 cells model showed an increase in ferritin concentrations, compared to the control (Sanz-Penella, Laparra, Sanz & Haros, 2012).

Differently processed amaranth grains (raw flour/flour from popped seeds; in scalded i.e. non-scalded variants) were included in spelt bread formulation in the study by Filipčev, Bodroža-Solarov, Pestić and Šimurina (2017).

Among the studied composite loaves of bread, the best bread quality (highest volume and softest crumb) was yielded by raw and scalded amaranth flour. But, in comparison to the control spelt bread, the effect was not significant. During storage for 6 days, the highest staling rate was observed with non-scaled amaranth flours (both raw and popped) though did not reach statistical significance.

Amaranth grain processed by popping was used to replace wheat flour in the range of 10 to 20% flour basis. The supplementation with popped amaranth grains resulted in an increased content of minerals (Zn, Mn, Mg, Ca) as well as squalene, from 8 to 12 times in comparison with the control wheat bread sample. Impairment of technological quality was evident through a decrease in loaf volume of supplemented bread samples from 3.54 to 2.36 mL g⁻¹ (Bodroža-Solarov et al., 2008).

Gluten-free bakery products represent a challenge to food technologists due to the poor technological quality of the final product. From the aspect of technological quality, satisfying scores were obtained for gluten-free bread from 100% amaranth that contained 60-70% popped amaranth flour and 30-40% raw amaranth flour. This type of bread showed

homogeneous crumb and higher specific volume (3.5 mL g⁻¹) than other gluten-free loaves of bread (Barca et al., 2010).

Cookies/biscuits

Cookies/biscuits are increasingly popular food products all over the world which are very good vehicles for many nutritious ingredients as their quality is less affected by wheat flour replacement i.e. gluten dilution effect, in contrast to yeast-leavened bakery products. Gluten is not a limiting constituent to determine cookie quality and a lower amount of wheat gluten is more advantageous for this product type. Sindhuja, Sudha and Rahim (2005) investigated composite flour cookies that contained 0-35% *A. gangeticus* flour. The addition of amaranth flour affected the dough's rheological properties by reducing water absorption capacity, notably lowering dough stability and increasing the mixing tolerance index. Pasting properties were also affected: reduced peak viscosity, cold paste viscosity and break down viscosity. The obtained cookies had improved surface colour (golden brown) and a crispier texture. Supplementation level at 25% of amaranth flour was found to be optimal with regards to sensory properties.

Inclusion of whole amaranth flour to cookie formulation at 20, 40, 60, 80 and 100% levels increased cookie diameter and spread, decreased hardness and a mean score of overall acceptability. Supplementation at a 60% level was an upper limit for sensory acceptable cookies (Chauhan, Saxena & Singh, 2016).

Inglett, Chen and Liu (2015) developed amaranth-oat composite sugar cookies. The pasting viscosities of amaranth-oat blends differed from that of wheat flour but were similar to amaranth flour. The cookie geometry and texture were affected by different proportions of amaranth and oat but the sensory quality remained unaffected and similar to wheat cookies. Amaranth-oat cookies had better nutritional properties and were gluten-free.

Chauhan, Saxena and Singh (2015) studied how germination affects the chemical, functional and pasting properties of amaranth. Flour from germinated grains was lower in fat (by 30%) and carbohydrates (by 3%) but higher in proteins (by 10%), fibres (by 35%) and antioxidant activity. Pasting properties were worsened. Cookies made from germinated amaranth flour were the softest and had a

medium spread (higher than wheat cookies but lower than raw amaranth cookies). Germinated amaranth cookies had enhanced nutritional composition with the highest values for total fibres and antioxidant activity. Their sensory properties were also acceptable. The study confirmed the suitability of germinated amaranth flour for use in cookie preparation.

Sabbione et al. (2019) reported potential health-beneficial features of gluten-free amaranth cookies. They found that after simulated gastrointestinal digestion, bioactive peptides associated with antithrombotic and antihypertensive activities were released.

PASTA

Many research works deal with the addition of amaranth flour or pre-processed and then ground amaranth flour to wheat semolina in different combinations. The obtained pasta had

improved nutritional value and increased functionality. Enrichment with amaranth mainly contributed to the enhanced value-added status of the final product.

In the work of Islas-Rubio, de la Barca, Cabrera-Chávez, Cota-Gastélum and Beta (2014) wheat semolina was partially replaced with a blend of raw and ground popped amaranth grain (90:10).

The suitability of several blend combinations (amaranth blend: wheat se-molina) was tested (25:75, 50:50, 75:25, and 100%, respectively) for pasta production. An increase in the proportion of amaranth blend yielded pasta with higher solid loss, lower weight gain and firmness. The enrichment of pasta with the amaranth blend reflected positively on its nutritional quality due to higher dietary fibre content and higher quality pro-teins.

Table 1.
Extrusion conditions and effects on amaranth grain

Extrusion conditions	Effects on nutritional composition	References
Blend of amaranth and corn flour (20, 35 and 50% w/w) – Twin-screw laboratory extruder; – Feed rate at 86 g/min (constant); – The temperature profile was fixed at 90 °C (first section) and 140 °C (end section).	– Higher retention of folate; – Decreased content of palmitic, oleic, linoleic and linolenic acid; – Extrusion reduced the detectable content of α -, β - and γ -tocopherol.	Ramos Diaz et al. (2017)
Raw amaranth flour – Laboratory single screw extruder, L/D ratio 15.5:1; – The temperature profile was fixed at 30 °C (first section), and 180 °C (end section).	– No significant difference in proximate composition between raw and extruded amaranth flour.	Menegassi, Pilosof & Areas (2011)
Amaranth-based porridge – Double screw inflating food machine; – Barrel temp. 130-170 °C; – Feed moisture 14-20%; – Optimized conditions: 14% feed moisture/169 °C.	– Decrease in polyphenols, phytic acid and Fe extractability; – Increase in Zn extractability; – Retention of A vitamin.	Akande, Nakimbugwe & Mukisa (2017)
Whole amaranth grains (lines <i>A. cruentus</i> and <i>A. caudatus</i>) – Brady Extruder Cooker cone opening <1.5 mm, temp. 154-163 °C, feeding rate 34 mm.	– No significant change in lysine level; – Increased net protein ratio (NPR); – Nutritional quality is equal or greater than casein.	Bressani, Sánchez-Marroquín & Morales (1992)
Raw amaranth flour – Single screw-extruder; – Constant rotation; – The rate at 75 rpm; – The temperature in the three zones of the extruder was regulated at 50 °C.	– Improves <i>in vitro</i> starch digestibility.	Garcia-Valle, Agama-Acevedo, Nunez-Santiago, Alvarez-Ramirez & Bello-Perez (2021)

Martinez, Ribotta, Añón and Leon (2013) reported a maximal replacement level of 30% w/w for wholemeal amaranth (*A. mantegazzianus*) flour to yield pasta of acceptable technological and sensory quality.

Partial replacement of wheat semolina with blends of amaranth flour and dried amaranth leaves had a positive influence on the nutritional properties and antioxidant capacity of pasta. The addition of amaranth flour and dry leaves decreased cooking time and luminosity values but increased cooking loss percentage. The addition of dried amaranth leaves contributed to increased iron, zinc, magnesium and potassium contents in comparison with control wheat pasta. Antioxidative activities were measured after cooking pasta and higher values were reported for pasta enriched with a combination of amaranth flour and dried amaranth leaves, which confirms the functional benefits of the pasta (Cárdenas-Hernández et al., 2016).

Gluten-free pasta production is a challenge for food technologists. Schoenlechner, Drausinger, Ottenschlaeger, Jurackova and Berghofer (2010) investigated the suitability of amaranth flour for gluten-free pasta production and showed that pasta from 100 % amaranth flour had low quality due to decreased cooking time, cooking tolerance and higher softness. However, the combination of gluten-free flours of amaranth (20%)/quinoa (20%)/buckwheat (60%) seemed most advantageous as it minimized the negative effects of each pseudo-cereal.

García-Caldera and Velázquez-Contreras (2017) investigated gluten-free formulation of pasta with corn starch (5-8%), tapioca starch (9-12%), rice protein (15%), albumin powder (4%) and amaranth flour (32%). According to a consumer test conducted by Mexican consumers, the final products rated in the following categories: for overall acceptability - neither like nor dislike i.e. for buying intention -maybe buy/maybe not buy that confirmed the suitability of amaranth as an ingredient in gluten-free pasta production.

EXTRUDED FOOD

Extrusion is a popular processing method that can be used to treat amaranth grains. Extruded amaranth grain products have a pleasant aroma and can be used as a snack food, supplement in

breakfast cereals, or as a raw material for further processing. The quality of extruded grains depends on numerous factors including initial moisture, temperature, pressure, screw speed, etc. During extrusion, starch granules undergo partial gelatinization and affect the expansion index of the final product. The addition of 20 or 50% of amaranth grits to corn grits decreased the paste viscosity in comparison to pure corn grits and decreased the quality of an extruded product by increasing its density and hardness and lowering the expansion index (Dokić, Bodroža-Solarov, Hadnađev & Nikolić, 2009). In contrast, the study of Ramos Diaz et al. (2013) showed that the highest expansion index was achieved in extrudates containing amaranth (20% amaranth 80% corn) whereas the lowest in pure corn extrudates. Extrusion conditions affected the expansion index in the following way: increased screw speed and initial moisture increased the expansion. The follow-up study of the same research group (Ramos Diaz et al., 2015) showed that extrudates containing amaranth were less crispy, crunchy and less adhesive due to disruption of internal structure that contributed to the formation of denser porosity. The dominant sensory attributes perceived by panellists were crispiness and crunchiness while roughness was decreased. The general conclusion was that amaranth along with other studied Andean grains (quinoa, kaniwa) are promising for use in snack product design.

Table 1. presents the effects of extrusion under different conditions on the nutritional composition of amaranth grains reported in the literature.

POPPED GRAIN

Popping is another suitable processing method for amaranth grains that yields a tasty puffy product. During this processing method, raw grains are subjected to dry heat (180-200 °C) for a short time which leads to starch swelling and expansion and volume increase (Bressani et al., 1992).

Popped amaranth has versatile uses: as an ingredient in confectioneries, snack and bakery products, as a breakfast cereal, porridge, etc.

Gamel and Linssen (2008) investigated the formation of volatile aromatic compounds during the popping of amaranth grains at 150-200 °C on a hot plate for 10 s. They found that the majority of volatiles in popped grains were

Table 2.
Popping conditions and effects on amaranth grain

Popping conditions	Effects on nutritional composition	References
– Temperature from 170 to 190 °C for 30 s.	– Heat treatment decreased the essential amino acid index to 85.4%; – Amino acids, valine and leucine contents decreased significantly.	Pisarikova, Kračmar & Herzig (2005)
– Temperature from 200 °C to 240 °C; – Load from 14 to 22 g; – Airflow from 0.013 to 0.015 m ³ s ⁻¹ – Moisture from 12% to 16%; – Temperature 260° C for 15 s.	– Completely gelatinised starch; – Protein content remained unchanged; – Increased available lysine content.	Lara & Ruales (2002)
– Hot pan. – Heating on an aluminium pan using an Ariston K3G2/G gas cooker.	– The content of B-group vitamins (B2, B3, B5, B7) is not affected; – No loss for essential and trace elements (Na, Mg, P, K, Ca, Cr, Mn, Fe, Co, Ni, Cu, Zn, Se, and Mo). – Low protein and lipid digestibility. – Heat treatment led to a reduction in protein digestibility (higher reduction during popping vs roasting); – No significant change in total phenolics but increased antioxidant activity.	Murakami, Yutani, Yamano, Iyota & Konishi (2014) Grundy et al. (2020) Muyonga, Andabati & Ssepuuya (2014)

Table 3.
Edible films based on amaranth grain

Amaranth grain component	Film formulation	Film characteristics	References
Flour	– 20.02 g glycerol/100 g flour and 29.5 g sorbitol/100 g flour.	– Good mechanical properties and low solubility.	Tapia-Blacido, Amaral Sobral & Menegalli, (2011)
Flour	– Stearic acid (5-15 g/100 g of flour) and glycerol (25-35 g/100 g of flour).	– Low solubility (15.2%), optimal barrier properties, oxygen permeability of 2.36x10 ⁻¹³ cm ³ m ⁻¹ s ⁻¹ .	Colla, Amaral Sobral & Menegalli (2006)
Protein	– Protein films were prepared by casting using glycerol as a plasticizer.	– Low water vapour permeability. – Poor mechanical properties.	Condes, Añón & Mauri (2013)
Protein+starch	– Protein isolate, glycerol and different concentrations of starch granules.	– The addition of starch nanocrystals improved film tensile strength and water vapour permeability as well as their water susceptibility.	Condes, Añón, Dufresne & Mauri (2018)
Starch	– Oxidation of isolated starch was done using sodium hypochlorite.	– Good tensile strength and water vapour permeability.	Sindhu & Khatkar (2018)
Starch	– Starch	– Higher solubility, greater paste clarity, intermediate peak viscosity/temperature and unique visco-elastic behaviour.	Chandla, Dharmesh & Sukhcharn (2016)

aldehydes formed by reactions of Strecker degradation such as 2-methylpropanal, 3-methylbutanal, 2-methylbutanal and phenylacetylenes contributed to the nutty, cornlike flavour and roasty odour of puffed amaranth.

Solanki, Indore, Saha and Kudos (2018) compared two popping methods on amaranth grains: a traditional one that uses a cooking pan and an improved method on a hot air

fluidized bed system. The traditional method is based on a hot surface (120-150 °C) up to 30 s covered with a lid. To increase the efficiency and speed, thermal treatment using hot air fluidized bed system was employed using the same temperature range. The improved method produced better popping characteristics (higher volume in the range 0.42-0.48 cm³, fold 5.3-6.1%, rate 44-65%). Iyota et al. (2005) also used hot air fluidized bed system for seed popping at 260 °C for 15 s and reported an 8.7-time increase in seed volume.

Inoue et al. (2009) developed an experimental continuous processing system for amaranth popping and optimized popping parameters. They revealed that maximum output and a high volume expansion ratio could be achieved if fan speed was increased with the gas temperature as they both affected the temperature of the fluidized bed.

Popping affects the nutritional composition. Most of the studies agree that several amino acids undergo degradation in nonenzymatic browning reactions (Marquez-Molina & Lopez-Martinez, 2020). Reported effects on the content of minerals span from no significant effect for essential minerals to a significant decrease in the content of Fe and Ca (Marquez-Molina & Lopez-Martinez, 2020). The decrease in minerals may be due to the loss of pericarp during popping. Table 2. Presents the effects of popping under different conditions on the nutritional composition of amaranth grains reported in the literature.

EDIBLE FILMS

Edible films based on starch and proteins have emerged as alternative environmentally friendly materials suitable for food packaging and food coating. In addition to biodegradability as one of the major quality requirements, edible films should fulfil a range of other quality attributes such as mechanical strength, fle-

taldehyde as well as alkylpyrazines, ethylpyrazine, vinylpyrazine, 2,5-dimethylpyrazine and 3-ethyl-2-5-dimethylpyrazine. These compatibility, and permeability to water vapour and gases, to adequately address the storage stability of foods.

Table 3. presents the formulations and characteristics of edible films based on amaranth grain or its isolated components reported in the literature.

BEVERAGES

Amaranth grain can be an excellent source for the production of different functional drinks intended for the general population and sportsmen. Due to its exceptional nutritional composition and functionality, it could be the main ingredient in designing low-calory, nutritious drinks.

Table 4. presents the formulations and characteristics of beverages based on amaranth grain or its isolated components reported in the literature.

MALTED FOOD

Partial hydrolysis of food is used to synthesise desirable and degrade antinutritional components. The commonly used method to achieve this is germination ie. malting (Berghofer & Schoenlechner, 2002; Demin, 2017).

Balasubramanian and Sadasivam (1989) studied the changes in the composition of amaranth grain following 192 h of germination and reported a decrease in starch content and increase in total sugars due to the activity of α -amylase and β -amylase. Proteins also decreased due to hydrolysis which liberated amino acids reflected through increased values for total lysine (by 31%), free amino acids, water-soluble proteins, and non-protein nitrogen. Increased protein digestibility (84%), the liberation of tannins and reduction in phytic acid and oxalates were the result of 48-hour germination of amaranth grains at 28 °C (Hejazi, Orsat, Azadi & Kubow, 2016). Effects of process parameters during the malting of amaranth grains were studied by Hejazi & Orsat (2016). They found that both temperature and time significantly influenced the content of total phenolics and antioxidant activities. Total phenols increased four folds in amaranth grains after 48 h germination at 26 °C. According to the overview of Marquez-

Table 4.

Beverages based on amaranth grain

Amaranth grain component	Beverage formulation	Beverage characteristics	References
– Amaranth proteins	– Proteins + gellan (0.015 or 0.035% w/v) and xanthan (0.020 or 0.045% w/v).	– Macro component contents very similar to those of skimmed milk; – Contains soluble fibres.	Manassero, Añón & Speroni (2020)
– Extruded amaranth flour	– Extruded amaranth flour (110 g) was added with	– 3903 µmol Trolox equivalents/100 g sample	Milan-Carrillo et al. (2012)
– Extrusion temperature 130 °C	– fructose (13 g), cinnamon powder (3 g) and vanillin powder (7 g) into purified	– 200 mL portion contributed to 15.5% - 25.5% of the RDI for antioxidants;	
– Screw speed 124 rpm	– water (1 L).	– Sensory acceptance btw “I like it” and “I like it extremely.”	
– Extruded/germinated amaranth flour	– Mixture 1 (70% extruded amaranth flour + 30% germinated chia flour) and	– Good quality proteins and dietary fibres;	Argüelles-López et al. (2018)
– Extrusion conditions: temperature 141 °C/screw speed 81 rpm; Amaranth grains mixed with lime (0.24% w/wt) and water (28% moisture);	– Mixture 2 (70% germinated amaranth flour + 30% germinated chia flour), respectively.	– Energy < 100 kcal;	
– Germination conditions: soaking 6 h, germ; Temperature 30°C, time 78 h.	– Each mixture was sweetened with no-calorie sweetener Stevia™, and vanillin powder (1 g).	– High sensory acceptability;	
– Amaranth grain (unspecified whether grains were used in native form or milled)	– 88.8 g of amaranth grains, 41.3 g of sugar, 0.35 g of sodium chloride, and grape or orange flavour per one litre of water	– Functionality is confirmed by high antioxidant and antihypertensive (ACE inhibitory) potential.	
		– Caloric content of the amaranth beverage 52.48 kcal per 100 mL;	Espino-González et al. (2018)
		– Equally effective as commercial sports beverages regarding hydration and performance support in cyclers.	

Molina & Lopez-Martinez (2020), several studies reported that germination activates the formation of soluble phenolics in the germinated seed. An increase in free, bound, and total phenolics in germinated amaranth seed as high as 1103, 600, and 829%, respectively, was reported by Perales-Sánchez et al. (2014).

Rathod and Udipi (1991) reported satisfactory performance of amaranth in three forms (malting, roasted, puffed) in mixed weaning foods with other cereals and leafy vegetables. Mean

intakes of weaning foods by children were between 58 g and 78 g, in this study.

Extensive research was conducted on the feasibility of amaranth grains in beer production. Experiments confirmed that amaranth has a potential for beer production (Zweytick, Sauerzopf & Berghofer, 2005; Meo et al., 2011; Gumienna & Górna, 2020; Habschied, Živkovic, Krstanovic & Mastanjevic, 2020). Beer from solely amaranth malt is gluten-free and has a specific intensive bitter taste (Habschied

Table 5.
Studies showing the health effects of diets based on amaranth food

Product type	Study type	Health effects	Reference
Extruded amaranth (EA) (lab. Single-screw extruder 150 °C, screw speed 200 rpm)	– An animal model with hypercholesterolemic rabbits	– Lower total cholesterol and LDL-C in rabbits fed with EA compared to those fed with AO; – 50% lower triglycerides and VLDL-C in comparison to the control group;	Plate & Areas (2002)
Amaranth oil (AO)		– No significant effects on HDL-C in all studied groups.	
Amaranth snack based on extruded grains	– 11 healthy female subjects	– Amaranth snack consumption induced higher insulin production and elevated glycemic index (107) relative to white bread (100).	Guerra-Matias & Areas (2005)
Amaranth snack based on defatted amaranth extruded on a single-screw extruder. 200 rpm speed, 150 °C, expansion rate 3-4	– Randomized double-blind clinical trial on 22 moderate hypercholesterolemic patients (11 males, age 30-65 yrs)	– A daily intake of 50 g of snack for 2 months did not significantly reduce LDL-C but did significantly reduce HDL-C.	Chavez-Jauregui et al. (2010)
Extruded amaranth	– An animal model with rats	– Ca bioavailability was increased in extruded amaranth compared to raw amaranth; – Apparent Ca absorption index, bone densitometry and fragility were not affected by amaranth processing but differed from the control (CaCO ₃ source). – Amaranth can be a source of dietary calcium.	Ferreira & Areas (2010)
Amaranth grain and oil	– An animal model with rats	– Diet based amaranth grain and oil lowered serum and hepatic cholesterol and triglyceride levels.	Shin et al. (2004)
<i>A. cruentus</i> grain and oil	– An animal model with hamsters	– Hamsters received a hypercholesterolemic diet (control, 10/20% grain, or 2.5/5% oil) for 4 weeks; – Absorption of cholesterol and bile acids, cholesterol lipoprotein distribution, hepatic cholesterol content, and cholesterol biosynthesis were affected; – Diet with amaranth grains lowered non-HDL cholesterol and raised HDL cholesterol whereas amaranth oil decreased total and non-HDL cholesterol.	Berger et al. (2013)
Amaranth oil	– Randomized placebo-controlled clinical trial on 125 patients with cardiovascular problems (coronary heart disease, hypertension accompanied with obesity)	– All patients got a low-salt diet and similar dietary recommendations. 3, 6, 12 and 18 ml of oil were administered daily for 3 weeks; – It was confirmed concentration-dependent cholesterol-lowering effect of amaranth oil; – Diet enriched with amaranth oil contributed to an increase in the concentration of polyunsaturated fatty acids, particularly, the long-chain acid of omega 3 families.	Martirosyan, Miroshnichenko, Kulakova, Pogojeva & Zolodov (2007)

et al., 2020). The beer is cloudy, and yellow with low foam stability (Zweytick et al, 2005). A detailed description of the malting process in the production of 100% amaranth beer is given in the study of Zweytick et al. (2005).

Unmalted amaranth grain is also suitable to partially replace barley malt. The composite beers had improved the mineral composition of beers by rising zinc and magnesium contents at only 10% replacement levels (Kordialik-Bogacka, Bogdan & Ciosek, 2019) and a more favourable amino acid profile (Bogdan, Kordialik-Bogacka, Czyzowska, Oracz & Zyzelewicz, 2020). Replacement of wort with unmalted amaranth significantly affected the flavour components of beer due to the formation of the different profiles of esters and higher alcohols.

FERMENTED FOOD AND BIOACTIVE PEPTIDES

The controlled activity of microorganisms is employed to produce fermented foods (Berghofer & Schoenlechner, 2002). Fermentation is recognized to improve the nutritional composition of food by synthesizing new compounds and altering or degrading the present compounds. Almost all amino acids increased in different fermented pigmented amaranth grains (Amare et al., 2015).

In the bakery industry, sourdough fermentation can be used to benefit the potential of various microorganisms. Jekle, Houben, Mitzscherling and Becker (2010) validated the potential of

several *Lactobacillus* species (*L. plantarum*, *L. paralimentarius* and *L. helveticus*) as starter cultures in amaranth-based sourdough. Castro-Alba et al. (2019) reported that controlled fermentation of amaranth flour with the starter culture Lp299v® resulted in mineral accessibility and bioavailability partially due to phytate degradation and enhanced mineral preservation during processing. Carbo, Gordu, Fernandez and Ginovart (2020) proposed a gluten-free sourdough formula containing 3 components (amaranth, buckwheat and quinoa). Sourdough was fermented with spontaneous microflora and consisted of lactic acid bacteria and non-*Saccharomyces* yeast populations. The dough was characterized by good pH stability and titratable acidity. The study proved the suitability of the sourdough for production of gluten-free bread and related products.

Sourdough from amaranth flour obtained by fermentation with different individual *Lactobacillus* strains contained higher concentrations of bioactive peptides in comparison to wholemeal wheat and barley sourdough but the content of lunasin, a cancer-preventive peptide, was less than two times lower (Rizzello, Nionelli, Coda & Gobetti, 2012).

Matejčekova, Liptakova and Valik (2016) analyzed the viability of probiotic *Lactobacillus* species in dairy and aqueous mashes based on amaranth flour. They concluded that probiotic *Lactobacillus* strains had appropriate densities after the fermentation in water-based amaranth mashes which may be useful for the design of non-dairy probiotic foods but additional research related to sensory acceptance is needed.

The potential health benefits of amaranth protein hydrolysates can be associated with the presence of bioactive peptides. Tironi and Anón (2010) demonstrated that naturally occurring peptides and polypeptides from *A. mantegazzianus* possess free radical scavenging capacity and the ability to inhibit linoleic acid oxidation. The primary antioxidative potential was enhanced by hydrolysis, especially alkaline, which contributed to the release of small peptides and/or amino acids with antioxidative activity. Despite difficulties in comparison with antioxidant capacities data, the present results suggest that amaranth is a potentially valuable source of antioxidative peptides. A further study by Delgado et al. (2016) managed to separate and identify 4 antioxidant peptides from *A. mantegazzianus* after a simulated gastrointestinal digest. All identified peptides belonged to the acid subunit of the 11S globulin. Another study to support the health-promoting effect of amaranth protein hydrolysates was the work of Mudgil, Omar, Kamal, Hilari and Maqsood (2019) who reported significant improvement in antioxidant, antimicrobial and antihemolytic properties of amaranth proteins upon hydrolysis. Kamal et al. (2021) demonstrated that amaranth protein hydrolysates contained anti-diabetic and antihypertensive peptides with high potential and implied their feasibility for use in the design of functional food.

OIL

Oil content in the seeds of *Amaranthus* spp. ranges from 5 to 10% (Saunders & Becker, 1984). Amaranth is an abundant plant source

of bioactive lipids such as squalene, unsaturated fatty acids, vitamin E as tocopherols, tocotrienols, and phytosterols. These compounds rarely coexist in common oils. Squalene, a highly unsaturated hydrocarbon from the triterpenoid family, is an extremely valuable constituent of amaranth oil since it affects cholesterol synthesis and serum cholesterol levels in humans and is a precursor of cholesterol in humans (Shin, Heo, Lee & Kim, 2004).

Amaranth oil can be derived by different technological techniques: cold pressing, hot extraction, supercritical CO₂ extraction, etc. which mainly affects the oil yield. Thus, the choice of oil extraction method in the grain of *Amaranthus* spp. is very important. In the study by Krulj et al. (2016), it was found that accelerated solvent extraction (ASE) gave the highest yield of the extracted oil (78.1 g kg⁻¹) and squalene (4.7 g kg⁻¹) from the grain of genotype *A. cruentus*. Bodroža-Solarov, Romanić, Dimić and Kuč (2005) compared the oil from *Amaranthus* sp. seed, obtained by cold-pressing and hot extraction. Cold-pressed oil had yellow-orange colour and a specific taste. The content of saturated fatty acids was 22.72%, while the content of oleic acid was 30.45% and linoleic, 37.39%. Cold-pressed oil showed extremely high durability which can be attributed to the presence of squalene and other bioactive components.

Amaranthus cruentus oil was found to have a high content of squalene (4.16 g kg⁻¹ of grain), and appreciable amounts (332 ppm) of n-alkenes (C23:1–C33:1) and n-alkanes (C23–C33). Although, the content of β-tocopherols was relatively high (546 ppm), owing to the fatty acid profile and esterified sterols, the oil was found to be susceptible to oxidative rancidity (León-Camacho, García-González & Aparicio, 2001).

HEALTH BENEFITS

In the overview study of Soriano-García and Aguirre-Díaz (2020), numerous health benefits of amaranth have been identified: inflammation reduction, bone health support, cardioprotection, gastroprotection, anticancer and antidiabetic effect, hepatoprotection, antimicrobial, antianemic and antimalarial properties, the gluten-free plant source of vitamins and proteins.

Several basic animal research studies and clinical research have demonstrated evidence that amaranth grain, oil or processed grains provide medical benefits (Table 5).

CONCLUSION

Amaranth is a prosperous crop relevant for domestic and industrial applications owing to its remarkable nutritional composition and bioactive ingredients that may be linked to beneficial health effects. Amaranth grains and their components have a wide range of food applications that include their usage as an ingredient in bakery products, pasta, extruded/expanded snacks, beverages, edible films, etc. Inclusion of amaranth in everyday diet would contribute to the consumption of more nutritious and balanced diets suitable for those adhering to gluten-free diets, too. These attributes justify more extensive research work on the diversification of amaranth product range and confirmation of their functionality and potential medicinal effects.

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PRIMENA ZRNA AMARANTHUS SPP. U ISHRANI

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Sažetak: Nedavno je došlo do ponovnog otkrivanja nekih drevnih useva zbog povećanih zahteva potrošača za zdravijom prehranom sa lekovitim i terapeutskim dejstvima. Jedna takva kultura je pseudožitarica *Amaranthus* spp. koja je nutritivno povoljnija od mnogih običnih žitarica i zadovoljava većinu zahteva moderne ishrane. Uključivanje vrsta amaranta u formulacije hrane proširilo bi asortiman prehrambenih proizvoda na tržištu. Visok nutritivni kvalitet i potencijalna funkcionalnost prehrambenih proizvoda od amaranta predmet su opsežnog naučnog istraživanja. Ova studija ima za cilj pregled trenutno dostupnih podataka o primeni zrna amaranta u prehrambenoj industriji i proizvodnji, i detaljno se fokusira na funkcionalnost ovih proizvoda, pružajući pregled trenutnog lanca vrednosti amaranta.

Ključne reči: štir, pekarski proizvodi, testenina, grickalice, jestivi filmovi, fermentisana hrana

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