Chapter

Effect of Various Process Conditions on the Nutritional and Bioactive Compounds of Amaranth

Ofelia Marquez-Molina and Leticia Xochitl Lopez-Martinez

Abstract

Amaranth is a pseudocereal with unique nutritional and nutraceutical profiles. Typically, the amaranth grain is consumed after some process such as cooking in water, popping, or extrusion which has been mentioned to affect the nutritional and nutraceutical characteristics. In this chapter, we will analyze the changes in amaranth grain on bioactive compounds (total phenolic content) and nutritional and nutraceutical properties (antioxidant activities) subjected to different processes. It has been shown that phytochemical and nutritional contents of amaranth grain provide health benefits such as antioxidant activity, anti-allergic action, antianemic effect, anticancer activity, and antihypertensive effect, besides the capacity of decreasing plasma levels, stimulating the immune system, and reducing blood glucose levels.

Keywords: amaranth, bioactive compounds, nutritional components, processing

1. Introduction

Amaranthus is a genus (family *Amaranthaceae*) consisting of more than 50 species (some are considered weeds, and others are cultivated for use as vegetables, ornamentals, and cereals) [1] and is a pseudocereal that was domesticated in America over 4000 years ago by the Aztecs and Mayas [2, 3]. The importance of amaranth has resurged in the last years due to agricultural features, since it is a fast-growing cultivar with tolerance to drought conditions, can grow in poor soils, and has important nutritional properties [4, 5]. Moreover, it has minerals, such as calcium, sodium, iron, magnesium, and vitamin E [6]. Polyphenolic compounds, such as phenolic acids and flavonoids, have been characterized in amaranth grains [7], which makes it an excellent source of bioactive compounds [8].

Typically, amaranth grain is not eaten raw and suffers a variety of processing methods in order to achieve desirable flavor, color, texture, and, sometimes, nutritional and nutraceutical properties. The different processing methods considered in this chapter such as cooking in water, toasting, fermentation, germination, or extrusion affect the nutritional and nutraceutical characteristics that have beneficial effects on human health [9–11].

The health benefits of amaranth come from nutrients and, in part, through the antioxidant characteristic of the phenolic compounds (non-nutrients) present in the grain, so that changes and variation in the composition and concentration of Nutrients and non-nutrients (such as the synthesis of phenolic compounds that may affect antioxidant activity) could indicate the type of amaranth grain processing that can preserve its nutritional and nutraceutical characteristics [8].

2. The nutritional and bioactive value of amaranth seeds

Amaranth seeds are rich in macronutrients such as proteins and have an outstanding balance of essential amino acids, as well as micronutrients including minerals [12, 13]. Pseudocereals such as amaranth are commonly rich in minerals with high calcium (Ca) content, potassium (K), and sodium (Na) are present in reasonable amounts, while zinc (Zn), copper (Cu), and manganese (Mn) in moderate amounts [14, 15]; more than 66% of total minerals were found in the bran and germ fractions in amaranth grain [16] and, in general, constitute rich source of iron (Fe), Cu, Mn, and Zn [13]. Based on the amino acid composition, amaranth seed protein is known to be of higher quality than most of the major cereal grains. The essential amino acid composition of amaranth grains from different *Amaranthus* species is summarized in **Table 1**. The lysine content is two to three times higher than that of the most common cereals, and sulfur amino acid content is also relatively high as compared with that of the most important legumes.

Amino acid	***A. caudatus***	***A. cruentus***	***A. hypochondriacus***
Aspartic acid	83.0	83.7	83.4
Threonine	41.7	45.8	49.3
Serine	86.1	83.9	ND
Glutamic acid	164	163.6	ND
Proline	31.5	31.3	ND
Glycine	77.3	70.0	ND
Alanine	56.3	56.4	ND
Cysteine	43.7	45.7	ND
Methionine	18.4	15.9	16.6
Valine	38.6	40.7	40.4
Isoleucine	26.9	28.7	32.5
Leucine	58.3	58.0	58.1
Tyrosine	47.4	45.6	47.2
Phenylalanine	43.2	44.4	ND
Tryptophane	18	19.4	ND
Histidine	31.2	30.6	ND
Lysine	54.8	53.5	53.7
Arginine	86.2	83.0	ND

Modified from Motta el al. [17]; Gamel et al. [18].

Table 1.
Content of amino acid profiles in (g/kg) of raw and processed amaranth varieties.

Several studies were focused on polyphenols in various *Amaranthus* species, which resulted in the identification of several phenolic acids (benzoic acid, ρ-hydroxybenzoic acid, vanillic acid, gallic acid, coumaric acid, ferulic acid, caffeic acid, syringic acid, protocatechuic acid, p-OH-benzoic acid, and isoferulic acid), flavonoids (quercetin, kaempferol and myricetin, isorhamnetin, rhamnetin), and their glycosides (quercetin 3-rutinoside, quercetin 3-o-glucoside) [19, 20].

3. The effect of processing on the nutritional and nutraceutical value in amaranth seeds

3.1 Cooking

Pseudocereals are consumed after cooking. However, culinary methods can lead to considerable losses of soluble nutrients such as amino acids, phenolic compounds, and, namely, minerals.

The few studies about the effect of cooking on minerals in amaranth grains have reported a significant decrease in iron (Fe) content during the boiling, due to the wet procedures which in general cause loss of dry matter and Fe; however, the content of zinc (Zn) was not affected. Roasting also reduced the content of this mineral but not the content of calcium (Ca) (**Figure 1**) [20]. The content of six amino acids increased after boiling and steaming compared with the raw seed (alanine, aspartic acid, glutamic acid, proline, tyrosine, and arginine).

Gamel et al. [21] investigated the effect of cooking on amaranth seeds of *A. caudatus* and *A. cruentus*. The seeds were washed with distilled water and then subjected to steam vapor in a closed water bath at normal pressure, until a soft texture was obtained. Steam reduced the content of phenolic compounds from 5.16 (raw) to 3.53 g/kg (cooked) and 5.24 (raw) to 3.96 g/kg (processed) in *A. caudatus* and *A. cruentus*, respectively.

Queiroz et al. [9] studied the effect of cooking on *Amaranthus cruentus* by immersing the grain in boiling water (100°C) for 10 minutes. The processing reduced the mean total phenolic content in amaranth grain from 31.7 to 24.10 mg of

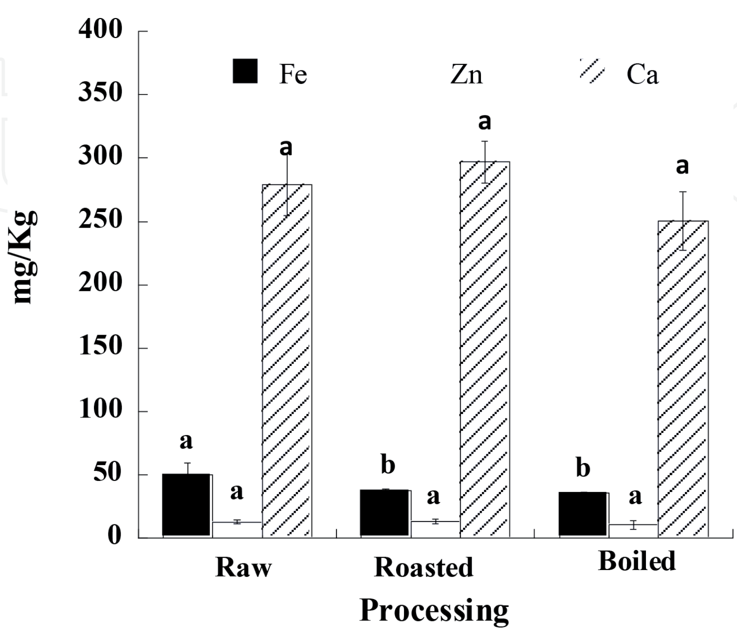

Figure 1.
Mineral composition of raw, roasted, and boiled Amaranthus (A. cruentus).

gallic acid equivalent/g; however, the antioxidant activity measured by the inhibition of lipid oxidation using the β-carotene/linoleic acid system increased from 55.42% in raw seed to 79.52% in the cooked seed.

3.2 Popping

Popping or puffing is one of the most popular ways to process amaranth grains, which imparts a pleasant flavor to the final product. In popping, the heat causes vaporization of water contained in the starch matrix increasing the temperature and pressure and the successive swelling and expansion of starch granules; the endosperm is transformed into a bubbly matrix, which solidifies through the evaporation of water, yielding a spongy structure [22].

Popping significantly decreased Fe and Ca content (31 and 8%, respectively). The decrease in Fe content could be attributed to the loss of pericarp during popping. Gamel et al. [18] reported that the levels of essential minerals (Mg, P, K, Ca, Mn, Fe, and Cu) were not affected by popping; Pedersen et al. [7] reported similar behavior for the levels of P, Ca, Fe, and C; on the other hand, no significant effect was observed on Zn and Mg content due to popping. It was concluded that the outer layer of amaranth grain contained high amount of Cu and Ca. In relation to the effect of processing on amino acids, **Table 3** shows that the content of several amino acids is decreased as a consequence of the popping. The loss of tyrosine was the highest, followed by phenylalanine, cysteine, and lysine; in a different study, Amere et al. [23] reported that aromatic amino acids were strongly affected, phenylalanine and tyrosine completely vanished, 90% of tryptophan vanished during popping, and nonenzymatic browning reaction is the most probable explanation for the decrease in the level of amino acids during heat treatment [24].

By the phytochemical way, Queiroz et al. [9] studied the popping process in *Amaranthus* grain (*A. cruentus*); the processing reduced the value of total phenolic content from 31.7 to 22.71 mg GAE/g. A similar behavior was found by Muyonga et al. [25], they found that the total phenolic content in *A. hypochondriacus and A. cruentus* ranged from 3.34 and 3.63 mg GAE/g from raw seeds, and popping altered the content of phenolics from 2.99 to 3.42 mg GAE/g; however, no significant differences were observed between raw and popped grains. In contrast, popping increased the content of total flavonoids from 0.47 to 0.78 mg GAE/g and 0.54 to 0.93 mg GAE/g of *A. hypochondriacus and A. cruentus*, respectively. Heat has been reported to cause a reduction in total phenolic content of popped grain amaranth [26].

3.3 Extrusion

Extrusion cooking is a high-temperature and short-time process in which moistened, expansive, starchy, and/or proteinaceous food materials are plasticized and cooked in a tube by a combination of moisture, pressure, temperature, and mechanical shear, resulting in molecular transformation and chemical reaction [27] which are able to break the covalent bonds, denature undesirable enzymes, and inactivate some antinutritional factors such as tannins and phytates [28].

Chávez-Jauregui et al. [29] determined the amaranth amino acid composition after extrusion at different moisture and temperatures; the result showed that the extrusion process did not affect the content of aspartic acid, glutamic acid, glycine, and lysine.

Data about the effect of extrusion on the phenolic content of amaranth seeds is scarce; Repo-Carrasco-Valencia et al. [30] examined amaranth seeds for the levels of phenolic compounds during extrusion, and they found that the levels show a decrease up to 80.3% of kiwicha (*Amaranthus caudatus*). This decrease may be due to decarboxylation of phenolic acids during extrusion.

3.4 Germination

During germination, dried amaranth seed absorbs water, the embryonic axis lengthens, the seed breaks dormancy and then protection responses arise through the synthesis of phenolic compounds [31]. Germination can cause changes in nutrients as well as the elimination of antinutrients such as enzymatic inhibitors in seeds [10].

Gamel et al. [18] studied the effects of germination of *Amaranthus caudatus* and *Amaranthus cruentus* seeds, and they found that there was no difference in sodium (Na), magnesium (Mg), iron (Fe), manganese (Mn), and copper (Cu) levels. However, calcium (Ca) (13 and 12%) and zinc (Zn) (14.3 and 13.5) increased in both species. These findings may be attributed to a decomposition of phytate or tannins that bind those minerals by enzyme activity such as phytase.

In a similar study, Gamel et al. [32] showed that germination of *Amaranthus caudatus* and *Amaranthus cruentus* seeds increased the contents of amino acids, aspartic acid, serine, alanine, valine, leucine, and lysine, and decreased the contents of threonine, arginine, tyrosine, and phenylalanine in both species. The valine content showed the highest increase and the tyrosine content the highest reduction.

Several studies have found that germination can gradually accumulate soluble phenolics in germinating seeds and sprouts compared with raw seeds. However, several studies have also reported a decrease. This behavior may be associated with the results expressed as wet or dry weight considering that the water content during germination is gradually increased during the germination process and can also depend on the time and temperatures used to germinate the seeds [33, 34].

For example, Perales-Sánchez et al. [35] optimized the germination conditions of amaranth seeds that would maximize the total phenolic and flavonoid content. In raw amaranth grains, the value of free phenolic content was 12.14 GAE/100 g, bound phenolic content 14.51 GAE/100 g, and total phenolic content 26.65 GAE/100 g. The germination bioprocess increased free, bound, and total phenolic contents of amaranth seeds by 1103, 600, and 829%, respectively, as in the case of total flavonoid contents whose content increases by 213%, when compared with the unprocessed material; in the same study, the in vitro antioxidant activity was assessed using the oxygen radical absorbance capacity (ORAC) assay and the ABTS radical cation decolorization assay, and they reported that the antioxidant activity, evaluated by ORAC assay, increased by 300%, while by ABTS method increased by 470% after germination.

Pasko et al. [36] studied the effect of sprouting on the content of total phenolic content of amaranth seed (*A. cruentus* Aztec and *A. cruentus* Rawa); the content of raw and sprout seed was from 2.95 to 250 mg/g and from 3.0 to 200 mg/g, respectively. The antioxidant activity was determined in raw amaranth seed that showed values of 12.71 and 11.41 mmol Trolox/kg for ABTS and 4.42 and 3.15 mmol Trolox/kg for DPPH, sprouting increased antioxidant activity according to the ABTS (220 and 150 mmol Trolox/kg) and to DPPH (149 and 250 mmol Trolox/kg) for *A. cruentus* Aztec and *A. cruentus* Rawa, respectively.

Data about the effect of germination on the phytochemicals of amaranth is contradictory. Gamel et al. [18] examined the levels of phenolic compounds at different germination states of two varieties of *Amaranthus*; they found that germinated seeds, followed by drying at 30, 60, and 90°C, decreased the contents of total phenolic compounds by 18.2, 19.3, and 33.7% in *A. caudatus* and 13.5, 35.8, and 41.1% in *A. cruentus*. They reported that drying the germinated seeds at high temperature (60 or 90°C) reduced their content of phenolic compounds compared with those dried at 30°C.

3.5 Fermentation

Fermentation is a process that involves lactic acid bacteria with a wide array of applications and is used in amaranth grains to increase the nutritional quality and remove undesirable compounds. Depending on the pH and temperature conditions, a fermentation process may modify the content and compositions of bioactive compounds such as phenolic compounds [37].

Fermentation showed an increase in Cu and Mg but no significant change in Zn and Ca. Motta et al. [14] found that levels of Fe, Zn, and Ca were not affected by boiling or steaming; however, a decrease in Mg and K is shown (**Table 2**).

The effect of fermentation on free amino acid content from different pigmented *Amaranthus* grains was studied by Amere et al. [23]; the results of the study showed that almost all amino acids increased. Tyrosine, glutamic acid and proline remained unchanged while arginine strongly decreased. Lysine and phenylalanine increased to a greater extent than the rest of the other amino acids; an explication to this behavior could be the protein hydrolysis during fermentation due to the enzymatic activity [38, 39].

Alvarez-Jubete et al. [8] determined the influence of fermentation in total phenolic content and antioxidant capacity (DPPH and FRAP) of raw and fermented grains of *Amaranthus*; they found changes of concentration from 21.2 to 82.2 mgGAE/100 g in raw and fermented grain, respectively.

Antioxidant capacity (DPPH and FRAP) also increased following fermentation as a response of one of the many metabolic changes that take place on the seeds: the increase in the activity of the endogenous hydrolytic enzymes.

3.6 Toasting

Toasting is a rapid processing method that uses dry heat for short periods of time that improves texture, enhanced crispness and volume due to puffing, and improves color, flavor, and shelf life of amaranth grains.

Repo-Carrasco-Valencia [30] studied the effect of toasting of kiwicha (*Amaranthus caudatus*) on iron, zinc, and calcium. Iron was reduced after being

Processing method	Cu	Mn	Fe	Zn	Mg	Ca	K	
Raw	Nd	Nd	150.5	31.9	3111	1470	Nd	Amere et al. [23]
Popped	Nd	Nd	106.7	32.4	3270	1350	Nd	
Fermented	Nd	Nd	176.5	33.4	3330	1460	Nd	
Raw	5.72	44.2	73.5	45.5	3280	2000	5520	Motta et al. [14]
Boiled	6.52	45.6	74.2	47.0	3070	2007	5380	
Steamed	6.01	43.8	72.5	46.8	3020	2005	5350	
Raw	6.0	6.3	139	52.0	2220	1907	3268	Mburu et al. [15]
Cooked	6.0	6.03	138	48.3	2219	1891	3244	
Raw	7.52	35.1	107	31.1	Nd	Nd	Nd	Murakami et al. [11]
Popped	8.7	37.8	114	33.8	Nd	Nd	Nd	

Nd, not determined.

Table 2.
Content of macro- and microelements (mg/kg) of raw and processed amaranth varieties.

Amino acid	*Amaranthus caudatus*			*Amaranthus cruentus*		
	Raw	**Popped**	**Extruded**	**Raw**	**Boiled**	**Steamed**
Cysteine	43.7	40.4	35.9	45	47	40
Aspartic acid	83.0	93.7	96.7	89.9	109	107.8
Serine	86.1	90.9	46.9	83.4	97.6	95.6
Glutamic acid	164.0	170.6	185.3	217.6	249.7	253.1
Proline	31.5	30.8	43.3	55.4	62.7	61.2
Glycine	77.3	84.4	84.7	105.2	120.7	116.3
Alanine	53.6	58.7	44.4	45.9	52.6	52.3
Valine	38.6	42.4	49.3	40.7	40.7	42.1
Tyrosine	47.4	34.8	32.7	39.8	44.9	46.4
Arginine	82.6	77.6	82.4	122.2	143.5	137.4
	Gamel et al. [18]			Motta et al. [17]		

Table 3.
Content of amino acids in (g/kg) of raw and processed amaranth varieties.

toasted from 5.0 to 3.55 mg/100 g, but the content of calcium and zinc was not affected.

Raw amaranth grain is sometimes processed by toasting the raw grain at high temperatures before it is milled into flour. This process provides increased protein quality and digestibility as compared with the raw product. However, some studies show that lysine is partially inactivated by roasting, for example, Bressani et al. [40] evaluated the roasting process in the lysine content on *Amaranthus cruentus* and *Amaranthus caudatus*, and they found that the lysine content decreased by 3 and 18.9%, respectively.

According to Queiroz et al. [9], toasting processes increased the content of total phenolic content from 1.35 to 20.3 mg of gallic acid equivalent/g with respect to raw grain; even so, however, the antioxidant capacity measured by lipidic oxidation was determined by the system ß-carotene/linoleic acid (55%). On the other hand, Muyonga et al. [25] analyzed the effect of toasting on total phenolic content and total flavonoids of *A. hypochondriacus and A. cruentus*; no significant difference in total phenolic content was observed between raw and toasted grain for both varieties of amaranth. Nonetheless, heat treatment generally led to an increase in the flavonoid content in grain amaranth, and this behavior could be associated with deactivation of endogenous oxidative enzymes, preventing enzymatic oxidation which causes loss of the antioxidant compounds in the raw plant materials. Muyonga et al. [25] showed an increase of 47.1 and 62.3% in *A. hypochondriacus and A. cruentus*, respectively.

Toasting resulted in a significant increase in antioxidant activity of both *A. hypochondriacus* (42.8%) and *A. cruentus* (62.3%); the antioxidant activity of plant materials is attributable to flavonoids and other phenolic compounds [41, 42]. Therefore, the increase in antioxidant activity might be due to the observed increase in total flavonoids.

In summary, amaranth grains are very rich in nutrients and non-nutrients such as total phenolic compounds and total flavonoids important for a diet with beneficial effects on human health. To consume amaranth it is necessary to be subjected to various processes to make it more palatable, without affecting or affecting as little as possible its nutritional content and bioactive compounds; the data indicated how different processing methods affect the mineral, amino acid, and phenolic content. With this information, it is possible to choose the best procedure to process amaranth in order to preserve or improve their nutritional and nutraceutical quality.

4. Conclusion

Processing resulted in important changes, on the minerals, amino acid, and phenolic content of amaranth seed.

A general decrease in the concentration of soluble compounds (Fe, Zn, and phenolic compounds) was observed in cooking (boiling and steaming), but it does not affect the amino acid content, which is affected by popping. In the case of total phenolics, toasting, fermentation, and germination showed a positive effect on its content; similar behavior was found for total flavonoids during popping. Regarding the antioxidant activity, it was not affected by the roasting process and increases during the steam treatment in relation to the raw amaranth grain. Germination exerts a positive effect on the content of minerals and total phenolic compounds. The insoluble fractions of amaranth grain have been less studied and need further investigation.

Amaranth seeds constitute an important food because of their nutritional characteristics. They are also a good source of minor compounds that are responsible for their different biological activities. Nonetheless, the proven health effects of raw amaranth grains, cooking, popping, fermentation, germination, and amaranth-based products have yet to be studied, and more in vitro and in vivo research is needed.

Conflict of interest

The authors declare no conflict of interest.

Author details

Ofelia Marquez-Molina[1] and Leticia Xochitl Lopez-Martinez[2]*

1 University Center of UAEM Amecameca, University Autonomous State of Mexico, State of Mexico, Mexico

2 CONACYT-Research Center for Food and Development, Hermosillo, Sonora, Mexico

*Address all correspondence to: leticia.lopez@ciad.mx

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