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# Nutraceutical value of kiwicha (*Amaranthus caudatus* L.)

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ABSTRACT

*Amaranthus caudatus* L. (Amaranthaceae), commonly known as kiwicha, is considered as one of the few multipurpose pseudocereal crops which supply higher nutritional seeds in huge quantities. *A. caudatus* is rich source of proteins, β-carotene, vitamins, minerals, and dietary fiber. Amaranth starch is of promising use by its high solubility and digestibility, compared to wheat, rice, and oat, seeds of amaranths are gluten-free and contain 30% more protein with complete set of amino acid, offering new possibilities for food processing, pharmacology, and cosmetics. In addition to its nutritional value, several studies have highlighted the importance of this *A. caudatus* as potential sources of biologically active compounds with anti-diabetic, anti-hyperlipidemic, and anti-hypercholesterolemic effects and antioxidant and antimicrobial activities. Therefore, the introduction in the diet of *A. caudatus* seeds could be associated with health promotion and prevention of diseases.

## 1. Introduction

The family *Amaranthaceae* is generally considered as the "Amaranth family." At the present time it is also called a third millennium crop plant. Based on taxonomical studies, the family is divided into two sections, namely *Amaranthus saucer* and *Blitopsis dumort*, with nearly an equal number of species. The section *Amaranthus* is dibasic with x = 16 and 17 (Rastogi & Shukla, 2013). According to FAO, the genus *amaranth* is mainly comprised of about 70 species, most of them native to America and only 15 species come from Europe, Asia, Africa and Australia. The division of species is based on their utilization method into grain amaranth, vegetable amaranth, ornamental, and weedy amaranth (Sauer, 1967). Grain amaranth has four species, that is, *A. hypocondricus, A. cruentus, A caudatus,* and *A. edulis* associated with three weedy species *A. hybridus, A. powellii,* and *A. quitensis* (Pal & Khoshoo, 1974; Rastogi & Shukla, 2013).

The genus *Amaranthus* generally includes monoecious annuals except some dioceous form (much restricted in distribution and has a branched and bushy appearance). The plant height varies from 0.3 m to 5 m among the various species. Leaves are oblong to elliptical in shape with the color ranging from light to dark green with some expressing red pigment throughout the genus. The inflorescence is very prominent, colorful, and terminal and contains one male flower per glomerule of nearly 100–250 flowers. The monoceious habit with predominant outcrossing in grain amaranth helped in their domestication (Pal & Khoshoo, 1974). The pollen grains are spherical in shape with poly ontoporate or golf ball like aperture in monoecious form. Seeds are small and lenticular averaging 1–1.5 mm in diameter with 1000 seeds weight ranged from 0.6 to 1.2 g (Jain & Hauptli, 1980; Saunders & Becker, 1984). The color of seeds varies species to species from pale ivory to black (Irving, Betschart, & Saunders, 1981; NAS, 1975; Pal & Khoshoo, 1974; Saunders & Becker, 1984). Seed embryo remain surrounded with the nutritive layer, thin wall perisperm cells being full of starch grains, and the protein bodies are embedded in lipid matrix (Coimbra & Salema, 1994; Rastogi & Shukla, 2013).

Amaranths are a leading group of plants among the pseudocereals that have the great potentiality to prevent malnutrition especially in the low-income food-deficient countries (Das, 2016). Pseudocereals are defined as fruits or seeds of non-grass species that are consumed in very similar way as cereals, and are effective supplements to them. Nowadays, Amaranth is considered as one of the few multipurpose crops which supply seeds in huge quantities that can be used in different ways, as pseudocereals, as tasty leafy vegetable of higher nutritional quality, and also as food and animal feed (Cheng, 2018; Coelho, Silva, Martins, Pinheiro, & Vicente, 2018; Das, 2016). Compared to wheat, rice, and oat, grain amaranths are gluten-free (Valcarcel-Yamani, da

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Silva, & Lannes, 2012) and contain 30% more protein with complete set of amino acid (Das, 2016) which can be processed as popped, flaked, extruded, and ground into flour. The word 'amaranth' comes from the Greek word 'amarantos' which means 'unwithering', this term was applied to amaranth to signify its hearty characteristics symbolizing immortality (Narwade & Pinto, 2018). Today the amaranth seeds are often known as kiwicha. It is cultivated in small scale in some discrete places of the world like Mexico, Guatemala, Peru, India, and Nepal. It has a bright prospect for further cultivation in USA and tropical countries (Alemayehu, Reta Bendevis, & Jacobsen, 2015).

The amaranth can grow under varied soil and agroclimatic conditions (Katiyar, Shukla, & Rai, 2000; Shukla & Singh, 2000), and is also resistant to heat and drought with no major disease problems (Barrio & Anon, 2010; Rastogi & Shukla, 2013; Robert, Hiroe, & Yotaro, 2008).

About 70 species of Amaranthus are distributed throughout the world in temperate, subtropical, and tropical climate zones. A few of them are distributed worldwide (Rastogi & Shukla, 2013). About 20 species are found cultivated/wild in India. Among grain types some species are considered as native to south and Central America (Grubben & Van Stolen, 1981) while some other types are native to Europe, Asia, Africa, and Australia (Becker et al., 1981). In its own country of origin, grain Amaranthus (*A. caudatus*) is known by various names like kiwicha. India has been considered as one of the centers of distribution of amaranth, the other center being tropical America (Rastogi & Shukla, 2013).

More recently, it has been suggested that China is the world's largest producer of amaranth, both for grain consumption and fodder plant use. Other important amaranth production countries are the United States, Canada and Argentina. However, there is no official data on world production levels (Coelho et al., 2018).

Besides the potentially important roles of diet and nutrition in cancer (Mayne, Playdon, & Rock, 2016), obesity, diabetes, cardiovascular disease (Mozaffarian, 2016) and neurodegenerative disorders, which are a leading cause of global death, the inclusion of good dietary sources might mitigate or prevent this damage (Montoya-Rodríguez, Gómez-Favela, Reyes-Moreno, Milán-Carrillo, & González de Mejía, 2015). Highly processed foods such as meats and sugar or sweetened beverages have harmful effects, whereas bioactive-rich foods like fruits, vegetables, nuts/seeds, beans/legumes, and whole seeds have protective effects (Micha et al., 2017). A healthy diet between the intakes of functional food might minimizing or prevent these diseases (Jew, AbuMweis, & Jones, 2009). Thus, in the last years, the research interest in bioactive food compounds as an alternative to pharmacological treatment has increased. The introduction in the diet of amaranth seeds has been associated with health promotion and prevention of diseases (Rastogi & Shukla, 2013).

Like other *Amaranthus* spp., *A. caudatus* (Amaranthaceae) has several features that make it an attractive crop, both in the Western world and in developing countries. In fact, *A. caudatus* readily adapts to new, demanding environments, including some that are inhospitable to cereals. Amaranths are a rich source of lysine, β-carotene, vitamins, minerals and dietary fibre (Gowele et al., 2019; Pedersen, Kalinowski, & Eggum, 1987). Amaranth also contains nitrates and oxalates, which are known as anti-nutrients. However, the anti-nutrients are present in small amount that does not cause any nutritional problem under normal condition of consumption (Prakash & Pal, 1991).

The agro-industrial uses of amaranth seed were described a few years ago as well as the first output of research towards processing and utilization of amaranth seed and its conversion into high-quality human food for infants (Achigan-Dako, Sogbohossou, & Maundu, 2014; Sanchez-Marroquin et al., 1986; Sanchez-Marroquin, 1983). Both amaranths and quinoa produce significant amounts of edible seed (Zheleznov, Solonenko, & Zheleznova, 1997), and they are richer sources of minerals and vitamins than most of the cereals (Vetter, 1994). That is especially true of amaranth which is considered as the seed of the twenty-first century (Vetter, 1994).

Amaranthus is an important nutritional crop. It is rare plant whose leaves are eaten as vegetable while seeds are eaten as cereal (Kauffman & Hass, 1983; Saunders & Becker, 1984). The spp. *A. caudatus, A. hypocondriacus,* and *A. cruentus* used for grain purposes has tremendous potential to increase the food production of a country. People use amaranth as vegetable and also as cereal in the bakery, cookies, biscuits, candies, pancakes, pasta, and noodles formation, etc. (Rastogi & Shukla, 2013).

In Peru and Bolvia, Amaranthus seeds are used as grain while in Mexico the seeds of *A. hypocondriacus* used as grain. From popped seeds they make candies and molasses. In Peru the seeds are popped and use as flour or bound with syrup to make bells. Seeds are mostly used to make laddoos in India and sometimes it is taken with rice after boiling with rice. In the Himalayan region, the seed flour is used to make chapattis while in Nepal the seed flour is used as satto. In the United States, the seeds are used to make crackers, cookies, and as cereal and also in the preparation of baked products. Most commercial product is the "breakfast amaranth." A traditional use of amaranth in Mexico and other countries is to mix popped amaranth with honey to make a type of snack bar or snack cake. Sometimes the whole seeds are used in a type of porridge or as a condiment or other foods (Rastogi & Shukla, 2013).

The most common use is to grind them into flour to use in the production of breads, pancakes, cereals, cakes or other flour based products. The grains can be popped or flocculated as porridge, being a food with cereal characteristics, being gluten-free and more nutritious (Coelho et al., 2018).

Wheat flour blended with high amaranth protein content can be used to enhance the nutritional worth of the final food products such as noodles, cookies, potatoes, cassava or maize breads and cakes. Amaranth can be used to substitute wheat and other grain products altering significantly the technological functional properties of the products. A study reported that amaranth grain starch maize could be used as a thickener in sauces (Singhal and Kulkarni, 1988a, 1988b). Various food processing technologies (e.g., germination and lactic acid fermentation) have been proposed as ways to improve nutrient density and reduce antinutrients (Hotz & Gibson, 2007). It was observed that the native starch of amaranth is resistant to freezing and thawing, and therefore, stable to some types of thermal treatment, although acidic conditions may limit its stability (Yanez, Zacarias, Granger, Vasquez, & Estevez, 1994).

Candy and snacks made from this grain are nutritious and widely consumed in Asia and South America (Singhal and Kulkarni, 1988a, 1988b). Amaranth snacks with good acceptance and high nutritional value have been developed by extrusion (Coelho et al., 2018).

Amaranth flour is frequently used in mixtures with maize or wheat to obtain a balanced source of proteins (Alvarez-Jubete, Wijngaard, Arendt, & Gallagher, 2010; Escudero, De Arellano, Luco, Gimenez, & Mucciarelli, 2004). Also, it has been reported that the nutritional value of bread could be enhanced with the addition of expanded amaranth grains (10–20%) as an alternative to amaranth flour, increasing iron, phosphorus, calcium, magnesium and potassium contents. (Bodroza-Solarov, 2008; Coelho et al., 2018; Pasko, Barton, Folta, & Gwizdz, 2007; Shukla et al., 2006).

The main research activities done on amaranths have been focused on its exceptional nutritive value due to the content of protein, fat and active substance with anti-diabetic, anti-hyperlipidemic (Sangameswaran & Jayakar, 2008), anti-hypercholesterolemic effects (Girija, Lakshman, Udaya, Sachi, & Divya, 2011) and antioxidant (Alvarez-Jubete et al., 2010; Tironi & Añon, 2010) and antimicrobial activities (Maiyo, Ngure, Matasyoh, & Chepkorir, 2010).

Several studies demonstrated the applicability of amaranth protein as a material for edible film production (Condes, Anon, Mauri, & Dufresne, 2015; Dieguez, Pelissari, do Amaral Sobral, & Menegalli, 2015). These studies have focused on film and coating development from natural polymers such as amaranth proteins and polysaccharides, and also lipids. A. caudatus flour films were developed and concluded that this material produced films with good gas barrier properties compared to other bio-based films. Although amaranth flour films were shown to be highly flexible, they showed relatively low mechanical strength (Tapia-Blacido, Sobral, & Menegalli, 2005). According to these authors, amaranth films have a complex structure, since they are not only formed by starch and plasticizers, but also possess significant protein and lipid content in their composition. Moreover, native lipids and water also acted as plasticizers, which produced an increase in the elasticity of the films and a reduction of its stiffness (Coelho et al., 2018).

Recently, considerable interest has been directed to microencapsulation of nutraceuticals in the prevention of diseases. Different studies have shown that biopolymers extracted from amaranth can be used as a microencapsulation material for hydrophilic and lipophilic compounds and as a source of bioactive compounds to be encapsulated (Coelho et al., 2018).

Iron deficiency anemia is a major public health problem in young children in developing countries and is associated with impaired cognitive development and morbidity. A nutraceutical formulation has been developed in a powder form that treats the prevalence of anemia in Mexican children, adolescents, and in general all adults in México. Commercial name is “Naturalmente Alegría”, and it has been approved by the Federal Committee for Protection from Sanitary Risks in Mexico (COFEPRIS). The product has been consumed by several thousands of Mexicans with anemia to date (Soriano-Garcia & Aguirre-Diaz, 2019).

Nowadays, amaranth is a traditional food mostly sold as an artisanal food product that has been signified as “functional food”, due to its beneficial properties that promote health (Loaiza, Lopez-Malo, & Jimenez-Munguia, 2016; Rojas-Rivas et al., 2019a, 2019b). In the market there are new products added with amaranth with characteristics of “superfoods” such as granolas, cookies or yogurts (Rojas-Rivas et al., 2019a, 2019b). This seed is added in different foods to improve its nutritional profile and its characteristics as a functional food. Amaranth is a kind of food with a wide nutritional content and which goes beyond its nutritional basic function, a characteristic of a “functional food” (Rivera, Bocanegra-García, & Monge, 2010). Amaranth is an excellent product that could be used to make gluten-free bread, especially for celiac consumers (Alencar, Steel, Alvim, de Morais, & Bolini, 2015; Alvarez-Jubete, Arendt, & Gallagher, 2009). However, consumers’ perception and consumption motives for traditional foods with functional characteristics need to be studied in their place of origin and from a sociological perspective (Rojas-Rivas et al., 2019a, 2019b).

## 2. Historical background and traditional uses

The most species of genus *Amaranthus* spp. (50–70 species in total) are native to the America, but there are at least 15 species native to Africa, Europe and Asia. There are a high phenotypic variations and interespecific taxonomic position (Joshi et al., 2018). The amaranth seed was first cultivated in the Americas. In the prehistoric period the oldest evidence fount was an archaeological excavation in a cave in Tehuacan, Mexico where seeds were dated 6000 years old. This elemental fact suggests that people used amaranth as a principal food in Central America during the Mayan and Aztec period (1400 s) (Zheleznov et al., 1997). Nevertheless, after the colonization of America, the use of amaranths significantly faded out and its utilization drastically decreased (Joshi et al., 2018).

Amaranth is one of the earliest known crop plants extensively cultivated and utilized by the Aztec people, who considered it a superfood. However, amaranth not only has been consumed for its seed, but also has been consumed for its leaves which are rich in proteins and micronutrients (Narwade & Pinto, 2018). For instance, in India and other Asian countries the leaves of amaranth are eaten like spinach, it is for this reason that the amaranth leaves has been known as “Chinese spinach” (Wong, 2017).

Over the last decades, this crop has been cultivated in some pockets of the world as merely traditional regional crop. Though, global interest in amaranth has been increased in the last few years for its multiple applications in the food industry, the discovered nutritive potentialities and other unique features that amaranth offer (Das, 2016).

At present, amaranth is a promising food crop mainly due to its resistance to heat, drought, diseases and pests (Calzetta Resio, Tolaba, & Suarez, 2000). Furthermore, the potential effect to mitigate climate change problems on global agricultural production for its crop productivity level between the less water requirement than other crops as wheat, maize and cotton (Venskutonis & Kraujalis, 2013). Due to all these reasons, amaranth crop may allow the support of food and nutritional demands of rural populations in agriculturally vulnerable areas.

On the other hand, both the seeds and leaves of amaranth have been traditionally used as natural remedies. For example, *A. caudatus* has been used as an antipyretic in Indian and Nepalese traditional medicine, as astringent, diuretic, antihemorrhagic and hepatoprotective agent (Basu & Kirtikar, 1987). *A. caudatus* has also been used to treat bladder distress, piles, toothache, blood disorders, and even dysentery (Madhava Chetty, Sivaji, & Tulasi Rao, 2008). The increasing awareness about the nutritional value, health benefits, medical and industrial uses of amaranth has resulted in the revival of the crop (Joshi et al., 2018).

## 3. Nutritional composition of *Amaranthus caudatus*

The amaranth seed is a pseudocereal which genus contains over 60 species which only three species of amaranth are used for edible seed production (*A. cruentus*, *A. caudatus* and *A. hypochondriacus*) (Narwade & Pinto, 2018). To understand the nutritional composition of amaranth and its protein value it is important to know how the amaranth seed is structured. The amaranth seed is very small (1–1.5 mm in diameter), is structured of different layers as the seed coat; the perisperm, rich in starch; the endosperm; and the embryo made up of the 2 cotyledons, highly in proteins; the procambium; the radicle; and the root (Montoya-Rodríguez et al., 2015) (Fig. 1).

Briefly, the nutritional value of the amaranths seeds are composed of 13–19% of protein, 5–13% of fat, 62–74% of starch (Chauhan, Saxena, & Singh, 2015; Montoya-Rodríguez et al., 2015; Tapia-Blacido, Mauri, Menegalli, Sobral, & Añon, 2007), 9% of dietary fiber (Chauhan et al., 2015), and 2.14–2.91% of ash (Chauhan et al., 2015; Tapia-Blacido et al., 2007). Table 1 summarized the nutritional composition from *A. caudatus*

The principal minerals in amaranth seed are Ca, Fe, Mg, Mn, K, P, S and Na, amaranth also is highly in vitamins of B complex (Becker et al., 1981; Montoya-Rodríguez et al., 2015; Zheleznov et al., 1997). Besides, nutritional features, amaranth are an attractive source of lysine, and other bioactive compounds such as phenolic compounds, squalene, folate, phytates, and tocopherols (Burgos & Armada, 2015).

### 3.1. Proteins

The protein composition of pseudocereals is similar to proteins of legumes and crucifers, however, qualitatively and quantitatively the protein of seed amaranths is higher than cereals and legumes (Marcone, 1999; Singhal and Kulkarni, 1988a, 1988b; Vilcacundo, Martínez-Villaluenga, Miralles, & Hernández-Ledesma, 2019). For instance, amaranth is highly composed of proteins than wheat (13.3%), maize (9.2%) or rice (7.0%) (Narwade & Pinto, 2018). The most dominant proteins in *Amaranthus* spp. are albumins and globulins with low or not detected levels of prolamins (Janssen et al., 2017). The amaranth species are slight differences among the protein contain, in average *A. caudatus* showed 13.5 g of proteins per 100 g of cereal by comparison to *A. cruentus* (15.7 g/100 g), and *A. hypochondriacus* (15.5 g/100 g) (Bressani, 1989; Mota et al., 2016). In addition, the amino acid proportion in isoleucine (52 mg/ g protein), lysine (67 mg/g protein), tryptopan (11 mg/g protein), threonine (51 mg/g protein), and sulfur-

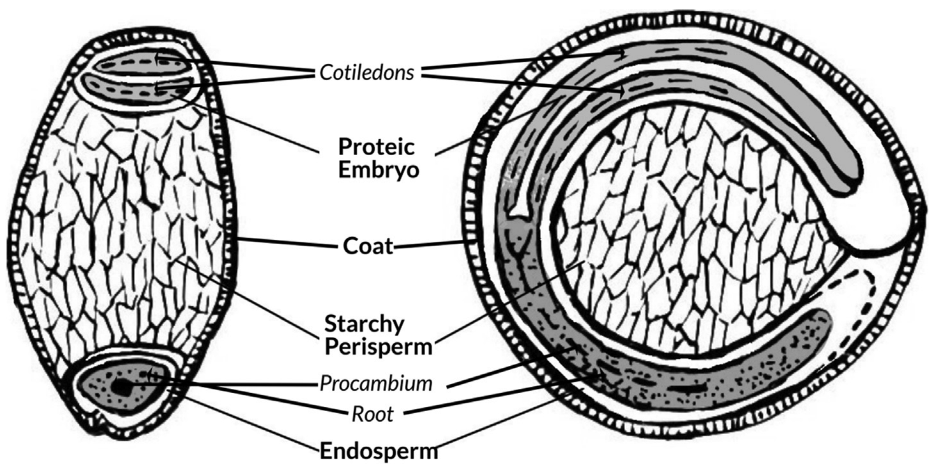



**Fig. 1.** Diagram of a cross and longitudinal sections from an *Amaranthus* seed. Four compartments can be distinguished within the mature seed: coat, embryo, endosperm, and perisperm. The distribution of main storage reserves is clearly different in those areas: the embryo and endosperm store proteins, lipids, and minerals, and the perisperm stores starch.

containing amino acids is higher in *A. caudatus* than other species of *Amaranthus* (Bressani, 1989; Mota et al., 2016), a comparison of amino acid composition of *A. caudatus* is summarized in Table 2 and schematized in Fig. 2. Usually, lysine appears as limiting amino acid in cereals, however, in amaranth is twice than wheat and thrice than maize (Joshi et al., 2018). The lysine value makes amaranth a high quality protein source (Valcarcel-Yamani & Lannes, 2012; Zheleznov et al., 1997). One of the reasons of these high quality is due to the availability of 65% of total proteins in the embryo (rich in lysine) of the seed and only the 35% in the perisperm (poor in lysine), on the contrary to other cereal seeds which concentrates its proteins in the perisperm (85%) (Das, 2016; Gorinstein et al., 2002; Gorinstein, Moshe, Greene, & Arruda, 1991; Grobelnik Mlakar, Turinek, Jakop, Bavec, & Bavec, 2010).

Otherwise, a measure of protein quality is the Protein Efficiency Ratio (PER), there are in seed amaranths ranges from 1.5 to 2.0; besides that, protein score is determined by taking the PER of the essential amino acids to the level for those amino acids recommended by FAO/WHO and multiplying by 100. For seed *A. caudatus* this score is 67–87, while in wheat is 47, in soybean 68–89, in rice 69, and in maize 35 (Valcarcel-Yamani & Lannes, 2012). In addition, the protein by amaranth cooked seeds have high digestibility approximately 90% (Becker et al., 1981; Das, 2016). Due to all these reasons the protein component of amaranth and its quantity are very similar to the levels recommended by FAO/WHO (WHO Technical Reports Series, 935, 1) and make it an ideal protein source for supporting human dietary needs.

### 3.2. Lipids

The lipid content is also higher compared to most cereal species, round 5–13% (Chauhan et al., 2015; Montoya-Rodríguez et al., 2015; Tapia-Blacido et al., 2007). *A. caudatus* lipid fractions are composed by triacylgrlycerols, phospholipids, squalene (7–8% and 11%) (Narwade & Pinto, 2018; Venskutonis & Kraujalis, 2013), lipid soluble vitamins as tocopherols and tocotrienols (5–8%) (Venskutonis & Kraujalis, 2013), and sterols (0.27–0.32 mg/g) (Plate & Areas, 2002). Other minor fatty compounds appear in the lipid fraction of amaranth seed as phytosterols, waxes, and terpene alcohols (Venskutonis & Kraujalis, 2013). Among phytosterols detected in the unsaponifiable fat fractions chondrillasterol was the most abundant in *A. caudatus* L (Bruni et al., 2001).

The fatty acid profile is rich in unsaturated fatty acids, round 73% of total fatty acids (Ayorinde et al., 1989), being majority linoleic (44.5–47.8%) and oleic acids (23.7–28.8%) (Alvarez-Jubete et al., 2009; Tapia-Blacido et al., 2007). In amaranth, the ratio unsaturated/saturated fatty acids is 2.7 and the ratio linoleic/α-linoleic is 52.4 (Alvarez-Jubete et al., 2009). These facts make amaranth as an attractive source of unsaturated fatty acids. The Table 3 shows lipid and fatty acid profile.

### 3.3. Carbohydrates

Amaranth starch granules are mostly composed to amilopectin (93.6–95.2%) to perform small granules in comparison to others cereal seeds (Venskutonis & Kraujalis, 2013). This structure leads to better properties in food industry utilization and shows higher strength to amylases action. For instance, amaranth starch shows unique gelatinization and freeze/thaw properties which could be beneficial to the food industry (Calzetta Resio et al., 2000). The features of starch like high solubility and digestibility are due to its uniquely small size, which is about one-tenth the size of cornstarch and therefore offer new possibilities for food, pharmacology and cosmetics industry. Amaranth starch types also have a higher glycaemic load; its consumption is related to a better physical performance and quicker recovery associated with intense physical activity and the reloading of glycogen storages

**Table 1**
Nutritional content from raw amaranth seed and raw amaranth flour.

| Nutrient | Raw amaranth | Raw amaranth flour (Chauhan et al., 2015) | Raw amaranth seed (Montoya-Rodríguez et al., 2015) | Raw amaranth flour (Tapia-Blacido et al., 2007) |
|---|---|---|---|---|
| Moisture (g/100 g) | 11.29 g | 8.13 ± 0.05 | | 7.97 ± 0.18 |
| Energy (kcal/kJ) | 371/1554 | 369.96/1546.43* | 393/1642.74* | 436.09/1822.85* |
| Protein (g/100 g) | 13.56 | 15.05 ± 0.05 | 13–19 | 14.21 ± 0.77 |
| Fat (g/100 g) | 7.02 | 6.68 ± 0.08 | 5–13 | 8.93 ± 0.03 |
| Ash (g/100 g) | 2.88 | 2.91 ± 0.08 | | 2.14 ± 0.03 |
| Carbohydrate (g/100 g) | 65.25 | 62.41 ± 0.03 | | |
| Sugar (g/100 g) | 1.69 | | | |
| Starch (g/100 g) | 57.27 | | 62 | 74.72 |
| Total dietary fiber (g/100 g) | 6.70 | 9.52 ± 0.02 | | |

* Calculated value from protein, fat and carbohydrate or starch reported values.

**Table 2**
Essential amino acid composition from *A. caudatus*.

| Nutrient | *A. Caudatus* g/100 g protein (Venskutonis & Kraujalis, 2013) | *A. caudatus* g/100 g protein (Montoya-Rodríguez et al., 2015) | *A. caudatus* g/100 g protein (Bressani, 1989; Mota et al., 2016) | FAO/ OMS/ UNU RDA* g AA/100 g protein |
|---|---|---|---|---|
| Isoleucine | 3.6–4.2 | 4.1 | 5.2 | 2.8 |
| Leucine | 5.7–6.4 | 6.3 | | 6.6 |
| Lysine | 4.8–5.2 | 5.9 | 6.7 | 5.8 |
| Sulfur amino acid | 4.5–4.7 | 4.9 | | 2.5 |
| Aromatic amino acid | 7.2–7.0 | 8.1 | | 6.3 |
| Threonine | 3.3–3.4 | 4.0 | 5.1 | 3.4 |
| Tryptophan | 1.1–1.8 | 1.1 | 1.1 | 1.1 |
| Valine | 4.5–4.6 | 4.7 | | 3.5 |
| Histidine | | | | 1.9 |

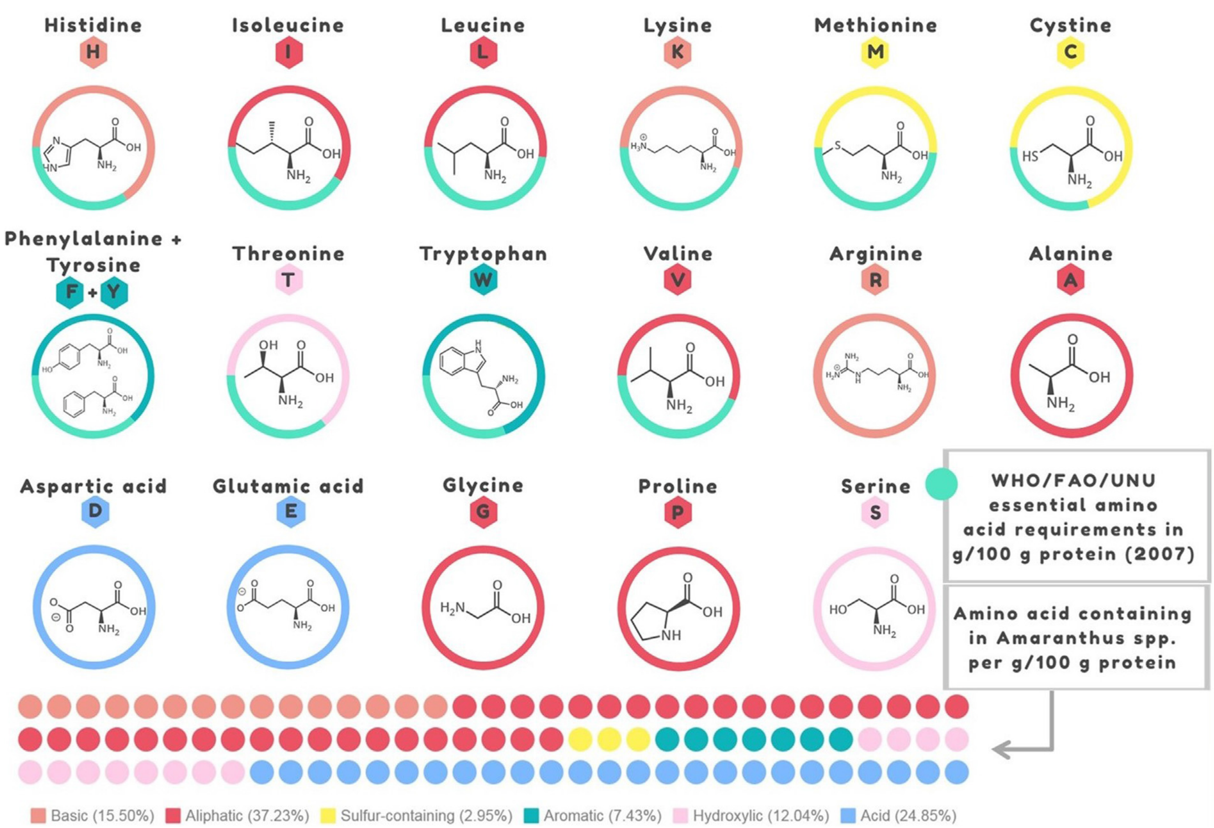



**Fig. 2.** Amino acid composition of *Amaranthus* spp. Values are expressed in grams per 100 g of protein: **H**, 0.389; **I**, 0.582; **L**, 0.879; **K**, 0.747; **M**, 0.226; **C**, 0.191; **F**, 0.542; **Y**, 0.329; **T**, 0.558; **W**, 0.181; **V**, 0.679; **R**, 1.060; **A**, 0.799; **D**, 1.261; **E**, 2.259; **G**, 1.636; **P**, 0.698; **S**, 1.148.

after exercise (Wright, 2005).

### 3.4. Vitamins and minerals

Regarding vitamins, a value of ascorbic acid (12.5 mg/kg) and those of B complex vitamins as niacin or B3 (28.0 mg/kg), pyridoxine or B6 (4.5 mg/kg), and riboflavin or B2 (2.4 mg/kg) has been reported in raw seeds of *A. caudatus L* (Gamel, Linssen, Mesallam, Damir, & Shekib, 2005). The vitamin value of amaranth seed is changed when the grain is cooked, popped, germinated or dried. For instance, if a high protein flour is made, the vitamin value goes up while the protein concentration increase in ascorbic acid (23.6 mg/kg), B3 (66.5 mg/kg), B6 (7.6 mg/kg) and B2 (4.9 mg/kg) (Gamel et al., 2005). The Table 4 is summarized the vitamin composition.

However, the most important vitamin identified in *A. caudatus* are different isoforms to E vitamin, as tocopherols and tocotrienols whit a total rank of concentration from 63.7 to 129.3 mg/kg (Bruni, Guerrini, Scalia, Romagnoli, & Sacchetti, 2002) as δ-(21.7–48.8 mg/kg), β-(19.5–43.9 mg/kg) and α-tocopherols (12.5–34.8 mg/kg) in major concentrations and γ-tocopherol (0.6–2.2 mg/kg) in minor concentration (Bruni et al., 2001, 2002). The interest in tocopherols and tocotrienols are that they act as natural antioxidants and their presence in oilseeds is often correlated with the relative abundance of unsaturated fatty acids. As well as their known action as antioxidants and free radical scavengers, they are also active against hypercholesterolemic atherosclerosis (Özer & Azzi, 2000).

In addition, *A. caudatus* is a rich source of iron (72–174 mg/L), calcium (1300–2850 mg/L), magnesium (2300–3360 mg/L) and zinc (36.2–40 mg/L) (Gamel et al., 2005). Amaranth has shown better amount of calcium, phosphorus and iron than rice and maize, and a comparable amount of iron in wheat (Nascimento et al., 2014). Table 5 summarized the mineral composition from *A. caudatus*.

### 3.5. Phenolic fraction and other phytochemicals

Total phenolic acids in several amaranth ecotypes from Peru ranged

**Table 3**
Lipidic and fatty acid profile from raw *A. caudatus* seed.

| Nutrient | Raw amaranth g/100 g | Amaranth flour g/100 g (Tapia-Blacido et al., 2007) | Amaranth g/100 g (Alvarez-Jubete et al., 2009) | DRIs* g/day (Dietary Reference Intakes, 2002/2005) |
|---|---|---|---|---|
| Saturated | 1.46 | | 26.9 ± 0.2 | |
| Monounsaturated | 1.68 | | 23.9 ± 0.1 | |
| Polyunsaturated | 2.78 | | 49.1 ± 0.2 | |
| Unsaturated/ saturated | | | 2.7 ± 0.0 | |
| Linoleic/α-linoleic | | | 52.4 ± 1.2 | |
| Total C18 *trans* | | | 0.0 ± 0.0 | |
| Phytosterols | 0.02 | | | |
| C14:0 | | 0.22 ± 0.00 | | |
| C16:0 | | 19.08 ± 0.01 | 20.9 ± 0.3 | |
| C16:1 | | – | | |
| C17:0 | | 0.62 ± 0.01 | | |
| C18:0 | | 4.10 ± 0.01 | 4.1 ± 0.1 | |
| C18:1 | | 28.82 ± 0.02 | 23.7 ± 0.1 | |
| C18:2 | | 44.48 ± 0.00 | 47.8 ± 0.2 | 17/12 |
| C18:3 | 0.042 | 0.89 ± 0.00 | 0.9 ± 0.0 | 1.6/1.1 |
| C20:0 | | 0.97 ± 0.00 | 0.8 ± 0.0 | |
| C20:1 | | 0.22 ± 0.00 | | |
| C22:0 | | 0.35 ± 0.01 | 0.4 ± 0.0 | |
| C24:0 | | 0.22 ± 0.00 | 0.4 ± 0.0 | |

* Dietary Reference Intakes (DRIs): Recommended dietary allowances and intake sufficient to meet the nutrient requirements of nearly all (97%-98%) in healthy adult.

from 18.3 to 40.1 and from 16.8 to 32.9 mg/100 g (dry weight) (Repo-Carrasco-Valencia, Hellström, Pihlava, & Mattila, 2010). Furthermore, several studies identified a phenolic fraction from *A. caudatus.* For instance, 52.4 g TAE (Tannic Acid Equivalents) per 100 g has been reported in a raw seed flour (dry weight) and also 68.6 g TAE per 100 g has been reported in high protein flour (dry weight) (Venskutonis & Kraujalis, 2013). However, the phytochemical composition depends on multiple variables in growing conditions; this has faced variable data in the literature consulted.

Based on the chemical composition of the total phytochemical fraction, the major polyphenolic compounds identified in *A. caudatus* L was. ferulic acid round 120–620 mg/kg, whereas vanillic acid (15.5–69.5 mg/kg), benzoic acids (4.7–136 mg/kg), caffeic acid (6.41–6.61 mg/kg) and p-coumaric acid (1.2–17.4 mg/kg) were detected in minor concentrations (Tang & Tsao, 2017; Repo-Carrasco-Valencia et al., 2010), besides that, gallic acid report a variable value, 11.0–440 mg/kg, in raw seed (Tang & Tsao, 2017). In addition, a

**Table 5**
Mineral composition from raw *A. caudatus* seed.

| Nutrient | mg/100 g | mg/L (Gamel et al., 2005) | g/100 g (Alvarez-Jubete et al., 2009) | DRIs* men/ women mg/ day |
|---|---|---|---|---|
| Ca | 159 | 1300–2850 | 180.1 ± 6.1 | 1000 |
| Fe | 7.61 | 72–174 | 9.2 ± 0.2 | 8/18 |
| Mg | 248 | 2300–3360 | 279.2 ± 1.1 | 420/320 |
| P | 557 | | | 700 |
| Zn | 2.87 | 36.2–40 | 1.6 ± 0.0 | 11/8 |
| Mn | 3.33 | | | 2.3/1.8 |

* Dietary Reference Intakes (DRIs): Recommended dietary allowances and intake sufficient to meet the nutrient requirements of nearly all (97%-98%) in healthy adult. (Dietary Reference Intakes, 2002/2005).

derivate of caffeic acid was detected in amaranth leaves (Schröter, Neugart, Schreiner, Rohn, & Ott, 2019). Table 6 summarizes the polyphenolic fraction in *A. caudatus* seed.

Additionally to these phenolic acids, some monomeric and dimeric flavonoids has been detected in *A. caudatus* seed samples as quercetin (214–843 mg/kg), kaempferol (22.4–59.7 mg/kg), isorhamnetin (42–600 mg/kg), rutin (7–592 mg/kg), among other minority flavonoids (Tang & Tsao, 2017; Venskutonis & Kraujalis, 2013). Table 7 shows some flavonoids identified in *A. caudatus*.

Other important phytochemicals have been identified in *A. caudatus*, as betalains (betacyanins and betaxantins) which are a class of red and yellow indol-derived pigments. The major betalains in *A. caudatus* are amaranthin (151.3 mg/kg) and isoamaranthin (58.7 mg/kg) (Tang & Tsao, 2017). In addition, *A. caudatus* extract shown 24.1 ± 1.29 mg/100 g of anthocyanins (Kabiri, Asgary, & Setorki, 2011), 17.7 mg/kg of betain, 5 mg/kg of isobetain, 3.55–4.29 mg/kg of lutein and 0.14–0.32 mg/kg of zeaxanthin (Tang & Tsao, 2017). The betalains are widely used as a natural food dye. However, the interests of betalains are grown for its antioxidant properties based on in vitro assays per food industry application.

Several triterpenoid saponins and glycosides were also isolated in the phytochemical fraction of *A. caudatus*. For example, Oleanolic acid 3-O-β-D-glucopyranosyl-28-O-β-D-glucopyranoside and 2β-Hydroxyoleanolic acid 3-O-β-D-glucopyranosyl-28-O-β-D-glucopyranoside among others were identified (Hussain, 2019).

## 4. Bioactive compounds in *Amaranthus caudatus*

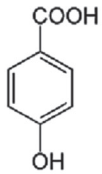
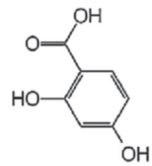
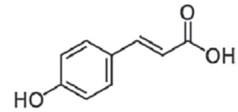
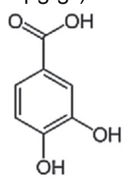
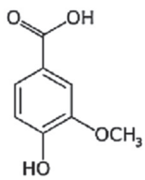
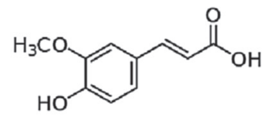
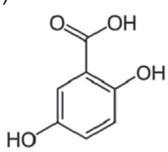
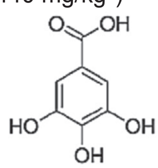
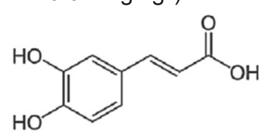
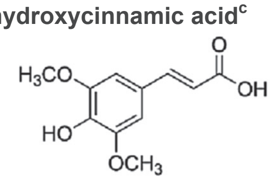
Currently, most diseases related to oxidative stress are of major concern worldwide as they can lead to economic losses in public health.

**Table 4**
Vitamin composition from raw *A. caudatus* seed.

| Nutrient | mg/100 g | Proteic flour mg/kg (Gamel et al., 2005) | mg/kg (Bruni et al., 2002) | mg/kg | DRIs* men/ women mg/day |
|---|---|---|---|---|---|
| Ascorbic acid | 4.2 | 12.5/23.6 | | 41.3–70.5 | 0.090/ 0.075 |
| B1 | 0.12 | | | 00.72–2.4 | 0.0012/0.0011 |
| B2 | 0.20 | 2.4/4.9 | | 1.8–2.7 | 0.0013/0.0011 |
| B3 | 0.92 | 28.0/66.5 | | 8.9–10 | 0.016/ 0.014 |
| B6 | 0.59 | 4.5/7.6 | | | 0.030 |
| B9 | 0.08 | | | | 400 |
| Total E | | | 63.7–129.3 | | 0.015 |
| α-tocopherol | 1.19 | | 12.5–34.8 | 2.97–34.81 | |
| δ- tocopherol | | | 21.7–48.8 | 0.01–48.79 | |
| β- tocopherol | | | 19.5–43.9 | 5.92–211.8 | |
| γ-tocopherol | | | 0.6–2.2 | 0.95–57.07 | |
| α-tocotrienol | | | | 10.2–20.6 | |
| δ- tocotrienol | | | | 15.5–18.4 | |
| β- tocotrienol | | | | 35.4–48.5 | |
| γ- tocotrienol | | | | 2.0–4.0 | |

* Dietary Reference Intakes (DRIs): Recommended dietary allowances and intake sufficient to meet the nutrient requirements of nearly all (97%-98%) in healthy adult. (Dietary Reference Intakes, 2002/2005).

**Table 6**
Major poliphenols (benzoic acids and cinnamic acids) from *A. caudatus* seed.

| | | |
|---|---|---|
| **p-Hydroxybenzoic acid** (8.5–20.9 mg/kg)  | **2,4-Dihydroxybenzoic acid** (4.7–5.1 mg/kg)  | **p-Coumaric acid** (1.2–17.4 mg/kg)  |
| **3,4-Dihydroxybenzoic acid** (4.7–136 mg/kg[a]; 13.6 ± 9.4 μg/g[b])  | **Vanillic acid** (15.5–69.5 mg/kg)  | **Ferulic acid** (120–620.0 mg/kg[a]; 203 cis/620 trans μg/g[b])  |
| **2,5-Dihydroxybenzoic acid** (trace[a])  | **Gallic acid** (11.0–440 mg/kg[a])  | **Caffeic acid** (6.41–6.61 mg/kg[a])  |
| **3,5-dimethoxy-4-hydroxycinnamic acid**[c]  | | |

[a]Tang and Tsao (2017).
[b]Venskutonis and Kraujalis (2013).

The discovery of different antioxidant and bioactive compounds, extracted from food sources, can be explored as natural new drug and functional food. *A. caudatus* has been ranked as one of the top five vegetables in antioxidant properties. These properties can be explained by the presence of antioxidant substances (Huerta-Ocampo & Barba De la Rosa, 2011) as phytosterols, polyphenols, vitamins, squalene, and bioactive peptides (Alemayehu et al., 2015; Campos, Chirinos, Ranilla, & Pedreschi, 2018; CW, 2017; Gowele et al., 2019; Schröter et al., 2018); which provide nutrients and might enhance the health or well-being of consumers.

Furthermore, in recent years, secondary metabolites of plant such as flavonoids, terpenes and alkaloids have drawn attention due to their diverse pharmacological properties as cytotoxic and anti-carcinogenic effects. The tendency to change synthetic antioxidants by natural ones has accelerated the research on vegetable sources like *A. caudatus* for identifying antioxidants. Nutritional and pharmaceutical research is increasingly focusing on nutraceuticals (Katan, 1999; Zeisel, 1999).

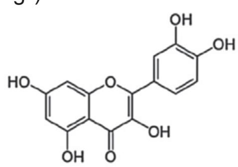
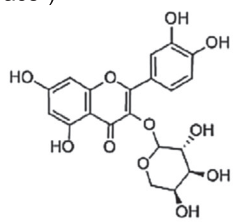
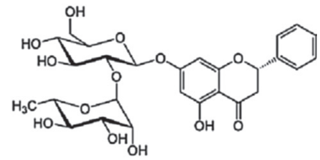
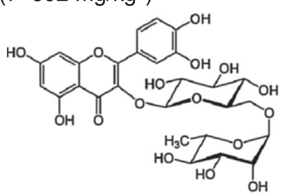
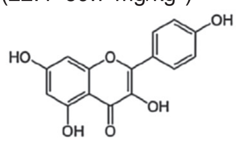
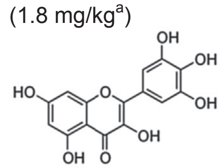
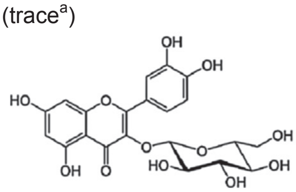
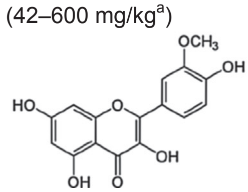
### 4.1. Bioactive peptides

Low molecular weight peptides are extracted from food proteins that are released during gastrointestinal digestion and food processing. These peptides can exert different biological properties such as antioxidant, anti-inflammatory, anti-hypertensive, and antibacterial activities. This has given rise to intensive research into the potential applications of food-derived multifunctional peptides in the prevention or the treatment of different diseases (Cicero, Fogacci, & Colletti, 2017).

Several bioactive peptides have been identified in *A. caudatus* L (Janssen et al., 2017; Vilcacundo et al., 2019). Low molecular weight peptides were the main responsible for the radical scavenging activity and the activity towards enzymes, while higher size peptides were the main determinant on the cytotoxic effects against colon cancer cells (Vilcacundo et al., 2019). Several studies have been reported different peptides with biological properties. For instance, 13 protein sequences were identified in two fractions from protein hydrolysates of *A. caudatus* (Vilcacundo et al., 2019) as YESGSQ, GGEDE and NRPET, in fraction one, and FLISCLL, TALEPT, HVIKPPS, SVFDEELS, ASANEPDEN and DFIILE in fraction two. These 13 peptides sequences contained the amino acid residues involved in enzyme binding at the N-terminal and C-terminal. The position of the amino acid residue might play an important role in α-amylase activity. The relation between the structure and bioactivities are that these peptides was identified as antioxidant and there are the ability to inhibit angiotensin converting enzyme (ACE), α-amylase, dipeptydil peptidase IV human (DPP-IV) (Vilcacundo et al., 2019). In comparison to others 4 peptides from protein hydrolysates by amaranth globulins, the bioactivity analyses arises similar DPP-IV activity at enzyme dimerization sites (Velarde-Salcedo et al., 2013). These peptides are larger than 13 residues, STHASGFFFFHPT, STNYFLISCLLFVLFNGCMGEG, GLTEVWDSNEQEF and TIEPHGLLLPS-FTSAPELIYIEQ GNGITGMMIPGCPETYESGSQ QFQGGEDE (Velarde-Salcedo et al., 2013).

Furthermore, other small peptides as YP, LPP, LRP, VPP, and IKP

**Table 7**
Major flavonoids (monomeric and dimeric flavonoids) from *A. caudatus* seed.

| | | |
|---|---|---|
| **Quercetin**<br>(214–843 mg/kg[a]; 6695 ± 219/7755 ± 685 mg/kg[b])<br> | **Quercetin 3-arabinoside**<br>(trace[a])<br> | **Naringin**<br>(trace[a])<br> |
| **Rutin**<br>(7–592 mg/kg[a])<br> | **Kaempferol**<br>(22.4–59.7 mg/kg[a])<br> | **Myricetin**<br>(1.8 mg/kg[a])<br> |
| **Isoquercetin**<br>(trace[a])<br> | **Kaempferol dirhamnoside**<br>(70 mg/kg[a]) | **Isorhamnetin**<br>(42–600 mg/kg[a])<br> |

[a]Tang and Tsao (2017).
[b]Venskutonis and Kraujalis (2013).

have been detected in amaranth seed protein hydrolysates. The IKP peptide has been described as one of the most potent inhibitor of ACE activity, showing antihypertensive action (Huerta-Ocampo & Barba De la Rosa, 2011).

The inhibitory peptides in amaranth seed proteins against dipeptidyl peptidase IV (DPP-IV) and angiotensin converting enzyme (ACE) activity have been identified and characterized (Bojórquez-Velázquez et al., 2018; Jorge et al., 2015; Velarde-Salcedo et al., 2013). Natural DPP-IV inhibitors are of great interest as therapy to promote a healthy life (Siró, Kápolna, Kápolna, & Lugasi, 2008). ACE-inhibitory drugs are used to control high blood pressure in hypertensive subjects. It was reported that the main source of ACE inhibitory peptides is fermented milk with IC50 values ranged from 0.47 to 1.70 mg/ml. Amaranth IC50 value was 0.6 mg/ml, which is in the range of milk peptides (Gonzalez-Gonzalez, Tuohy, & Jauregi, 2011).

The in vitro immunomodulatory effect of amaranth has been reported by SSEDIKE peptide which possessed a modulator capacity of activated CACO-2 cells to suppress the expression of inflammatory genes (Moronta, Smaldini, Docena, & Añón, 2015). Not only small peptides reported healthy effects, also *A. caudatus* lectin fraction might exerts a cytotoxic effect that would promote apoptosis in cancer cell, in addition to inhibiting cell adhesion (Quiroga, Barrio, & Añón, 2014).

Therefore, *A. caudatus* and other amaranth species proteins might start to gain importance as ingredients for functional foods for the prevention and management of chronic diseases related to oxidative stress, hypertension and/or diabetes (Orona-Tamayo, Valverde, & Paredes-López, 2019). Table 8 summarized bioactive peptide contents in amaranths.

### 4.2. Polyphenolic compounds

Polyphenols are secondary plant metabolites that play a role in the protection of plants against ultraviolet radiation, pathogens and herbivores (Harborne & Williams, 2000). Several hundred molecules with polyphenol structure have been identified in edible plants (Manach, Scalbert, Morand, Rémésy, & Jiménez, 2004). Fruit and beverages, such as tea, red wine, and coffee, are the main sources of polyphenols, however, vegetables, cereals and leguminous plants are also good sources (Alvarez-Jubete et al., 2010; Manach et al., 2004).

Polyphenolic compounds have antioxidant function acting as electron donors, electron acceptors, decomposer of peroxides and hydroperoxides, metal activators and deactivators and UV absorber (Svobodová, Psotová, & Walterová, 2003). Studies have shown that the amaranth seed have an antioxidant potential (Alvarez-Jubete et al., 2010).

Rutin (quercetin-3-O-rutinoside) and quercetin (the precursor of rutin) are flavonoids ubiquitously found in nature and in *A. caudatus* L which may be useful for the prevention and treatment of different types of cancer. Both, rutin and quercetin, are also important antioxidants properties and produce a significantly inhibition of the oxidation of high-density lipoprotein (HDL) cholesterol (Kalinova & Dadakova, 2009).

However, the principal antioxidant compound detected by HPLC in ethanol extracts of A. caudatus were caffeic acid and vainillic acid (Conforti et al., 2005)

### 4.3. Phytosterols

Phytosterols are bioactive compounds found in foods of plant origin. Clinical studies consistently indicate that the intake of phytosterols

**Table 8**
*Bioactive peptides* from *Amaranthus*.

| Bioactive Peptide/Peptide fraction | Function | Type of amaranth |
|---|---|---|
| YESGSQ, GGEDE, NRPET<br>FLISCLL, TALEPT, HVIKPPS, SVFDEELS, ASANEPDEN, DFIILE | Antioxidant and antihypertensive (ACE, α-amylase and DPP-IV inhibition) | *A.caudatus*[a] |
| STHASGFFFFHPT, STNYFLISCLLFVLFNGCMGEG, GLTEVWDSNEQEF, TIEPHGLLLPSFTSAPELIYIEQGNGITGMMIPGCPETYESGSQ QFQGGEDE | Antihypertensive (DPP-IV inhibition) | *A.hypochondriacus*[b] |
| YP, LPP, LRP, VPP, IKP | Antihypertensive (ACE inhibition) | Different species of *Amaranthus*[c] |
| Peptides from GBSSI, Alb1H48, GlobH48, GluH24, Diprotin A and Sitagliptin fractions | Antihypertensive (ACE and DPP-IV inhibition) | *A.hypochondriacus*[d,e] |
| SSEDIKE | Immunomodulatory | *A.hypochondriacus*[f] |
| NEAAALFR, SIFQFPK, RYVTFK, ILDPLAQFEVEPSK, TYDGLVHIK, LSTDDWILVDGNDPR | Antitumoral | *A.caudatus and A.mantegazzianus* [g] |
| Peptides from total protein hydrolysates, albumin, globulin and glutelin fractions | Antihypertensive, antioxidant, antitumoral, hypocholesterolemic, antimicrobial and antidiabetic | *A.hypochondriacus*[h] |

[a] Vilcacundo et al. (2019).
[b] Velarde-Salcedo et al. (2013).
[c] Huerta-Ocampo and Barba De la Rosa (2011).
[d] Bojórquez-Velázquez et al. (2018).
[e] Jorge et al. (2015).
[f] Moronta et al. (2015).
[g] Quiroga et al. (2014).
[h] Orona-Tamayo et al. (2019).

(2 g/day) is associated with a significant reduction (8–10%) in levels of low-density lipoprotein (LDL) cholesterol. Foods enriched with phytosterols are usually used to achieve the recommended intake (Cabral & Klein, 2017).

Phytosterols are present in the unsaponifiable fraction of plant lipid matrices which may act as inhibitors of cholesterol absorption as they compete for this substance at the intestinal level (Heinemann, Axtmann, & Bergmann, 1993). The majority of squalene was identified on the unsaponificable fraction of *A. caudatus*, round 80% of total unsaponificable fraction (Bruni et al., 2001). It has been reported values from 1.0% to 11.19% squalene/oil, depending on the amaranth cultivar/specie analysed (D'Amico & Schoenlechner, 2017; He & Corke, 2003).

### 4.4. Bioactive pigments

The carotenoids are effective in scavenging reactive oxygen species (ROS) formed in physiological processes. Biological molecules as DNA, protein, lipids and carbohydrates can be damaged by ROS (Kumpulainen & Salonen, 1999). Amaranths had high β-carotene concentrations which could provide most of vitamin A's recommended nutrient intake (Gowele et al., 2019; Khoo, Prasad, Kong, Jiang, & Ismail, 2011).

Anthocyanin is demonstrated to have powerful antioxidant properties against low-density lipoprotein oxidation to reduce the risk of the coronary heart disease (Wallace, 2011). Anthocyanins seem to have a clear effect on endothelial function and myocardium protection, have an effect on cholesterol distribution, protecting endothelial cells proinflammatory signalling and, in macrophages, anthocyanins inhibit LPS induced nitric oxide biosynthesis (Wallace, 2011).

### 4.5. Terpenoids

Squalene is a terpenoid compound derived primarily from the shark, although this component is also widespread in the unsaponifiable fraction of plant oils. Its importance as a dietary supplement is linked to its capacity to reduce cholesterol and triglyceride levels as well as to enhance the effects of some cholesterol lowering drugs (Chan, Tomlinson, Lee, & Lee, 1996; Chaturvedi, Sarojini, & Devi, 1993). Amaranth seeds are rich in squalene and has been consider as an alternative source of dietary squalene (Achigan-Dako et al., 2014; Bojórquez-Velázquez et al., 2018).

Moreover, dietary squalene is also supposed to play a role in tumor prevention (Rao, Newmark, & Reddy, 1998). It has been hypothesized that the chemopreventive effect of extra virgin olive oil on breast cancer may be due at least in part to squalene and phenolic antioxidants (Escrich, Solanas, Moral, & Escrich, 2011).

## 5. Biological activities of *A. caudatus*

Amaranth has been utilized for multiple purposes as part of indigenous medicinal practices all over the world and it is still in use. Different parts of the amaranth plant has been used as a diuretic, as a cough and cold remedy, treatment of urinary and throat infections, alleviation of gastric problems, dermatologically related issues, high blood pressure and tapeworms (Alemayehu et al., 2015; Caselato-Sousa & Amaya-Farfan, 2012).

Both, in vitro and *in vivo* studies report that a supplementation of different amaranthus compounds used as a supplement or an ingredient for functional foods may improve some cardiovascular disease risk, such as the reduction of systolic blood pressure, lowering cholesterol level conditions (Arikawa & Areas, 2002), and anti-atherosclerotic effect (Kabiri, Asgary, Madani, & Mahzouni, 2010). Moreover, *A. caudatus* has been reported for its anthelmintic (Kumar, Lakshman, Jayaveera, Nandeesh et al., 2010), antinociceptive (Kumar, Lakshman, Jayaveera, Shekar, & Muragan, 2010), antipyretic, anticancer, anti-allergenic, α-amylase inhibition (Conforti et al., 2005; Kumar et al., 2011), stimulation of the immune system and hepatoprotective activities in relation to its antioxidant power (Ashok et al., 2011). The main biological activities of *Amaranthus caudatus* are summarized in Fig. 3.

### 5.1. Antioxidant activity

It is widely accepted that vegetables play an important role in preventing the development of cardiovascular diseases, ageing-related diseases, obesity and cancers and even improving human memory (Bidlack, Omaye, Meskin, & Topham, 2000). These effects of are attributed to their natural dietary antioxidants which prevent free radicals related to ageing such as reactive oxygen species in the human body (Nilsson, Stegmark, & Akesson, 2004). The free radical theory of ageing involves cumulative damage through natural free radical oxidative changes, which results in increasing antigenicity, protein

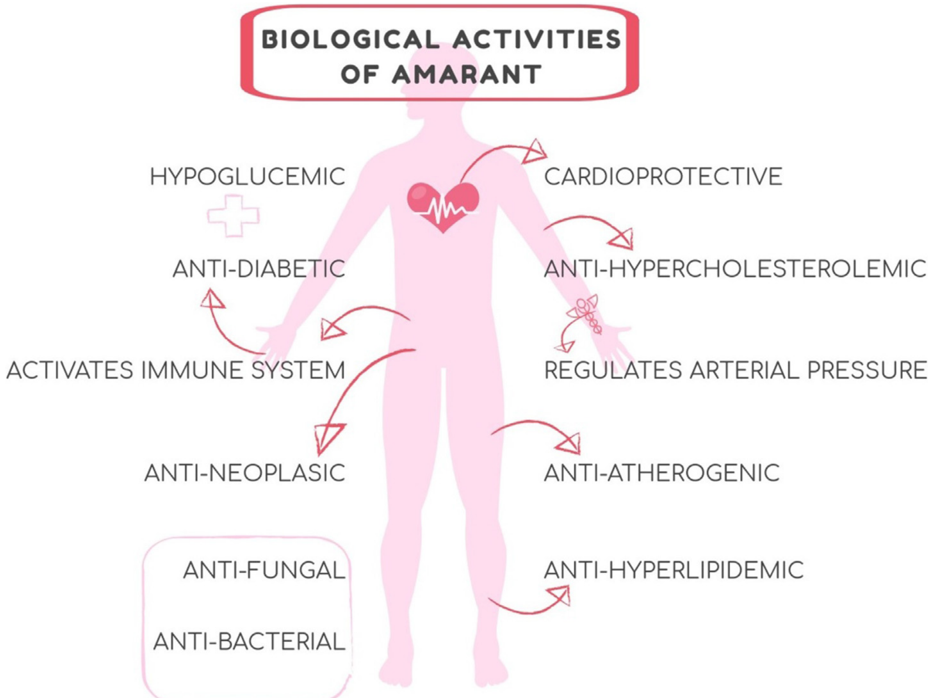



**Fig. 3.** Schematic representation of the main biological activities of *Amaranthus caudatus.*

changes and oxidative DNA damages (Sharlin & Edelstein, 2010).

For these reasons, the identification of new antioxidants represents a highly enhanced research area. Plants are some of the most attractive sources of new drugs compounds and have been proven successfully in the treatment of a number of disorders, in fact, several studies have shown that the possible benefits of antioxidants from plant sources lie in changing or reversing the negative effects of oxidative stress. Antioxidants-rich foods may be used to prevent diseases (Paredes-Lopez, Cervantes-Ceja, Vigna-Perez, & Hernandez Perez, 2010).

*A. caudatus* seeds contains significant amount of phenolic acids and flavonoids that exhibited antioxidant activity (Kalinova & Dadakova, 2009; Pasko et al., 2011). A number of studies have focused on the biological activities of phenolic compounds, which are potential antioxidants and free radical scavengers. It was found that a methanolic extract of A. caudatus contain 48% total phenolic fraction (Kumar et al., 2011). These extracts showed a strong antioxidant activity with effective scavenged properties (Kumar et al., 2011; Peiretti, Meineri, Gai, Longato, & Amarowicz, 2017). Some results suggest that tannin from the leaves of A. *caudatus* is a promising source of antioxidant component that can be used as a food preservative or nutraceutical (Jo et al., 2015). Squalene has been detected in two varieties (Oscar blanco and Victor red) of *A. caudatus* grown in Bolivia and greatly contributed to the in vitro lipid peroxidation inhibitory activity (Campos et al., 2018; Conforti et al., 2005). A recent study shows the capacity of bioactive peptides from *A. caudatus* to inhibit lipid peroxidation and the production of ROS in zebra fish embryo model (Vilcacundo et al., 2018).

### *5.2. Cardioprotective properties*

The nutraceutical research sector which shows the greatest development is linked to the identification of plant species that can be used to produce dietary supplements to counteract the onset of pathologies related to fat and cholesterol consumption in the diet (Jenkins et al., 1999). Various classes of chemical compounds are deemed to be co-responsible for hypocholesterolemic activity, and many of these are present in the lipid fraction of oleaginous seeds.

The *A. caudatus* oil has been shown to prevent hypertension and cardiovascular disease. Regular consumption of amaranth could reduce cholesterol levels and blood pressure (Bruni et al., 2001; Cabral & Klein, 2017; Chaturvedi et al., 1993).

Some studies have revealed the antihypercholesterolemic effects with potential for the prevention of coronary heart diseases of *A. caudatus* seeds. The intake of a diet including *A. caudatus* flour for 21 days significantly decreased the total cholesterol and LDL-cholesterol concentrations while the triglycerides contents were 50% lower in hypercholesterolemic rabbits compared to the control treatment (Plate & Areas, 2002). These effects were likely attributed to the dietary fiber, squalene, and protein in *A. caudatus* In another study, hydroalcoholic extracts of *A. caudatus* showed antihypercholesterolemic and anti-atherogenic effects associated with the reduction of serum lipids and oxidative stress markers in high cholesterol-fed rabbits (Kabiri et al., 2011).

Several studies have shown that amaranth seed or oil may benefit hypertension and cardiovascular disease, regular consumption reduces blood pressure and cholesterol levels, while improving antioxidant status and some immune parameters (Achigan-Dako et al., 2014; Alemayehu et al., 2015)

The dyslipidemia is characterized by increase in total cholesterol, LDL, VLDL (Very Low Density Lipoprotein respectively), triglycerides and low HDL (High Density Lipoprotein). A study showed that this altered serum lipid profiled was reversed towards normal after treatment with methanol extracts of *A. caudatus* L (Girija et al., 2011). Hypocholesterolemic effect of different amaranth products was studied both in animal models, and in humans (Chmelik et al., 2013). In addition, *A. caudatus* extract, compared with lovastatin, significantly decreased the cholesterol, LDL-C, triglycerides, oxidized LDL (Ox-LDL), apo-lipoprotein B (apoB), atherogenic index (AI) whereas HDL-C and apo-lipoprotein A (apoA) increased (Kabiri et al., 2010).

Methanol extracts of three plants of Amarathus which includes *A. caudatus* showed significant anti-hyperlipidemic effect providing the scientific proof for their traditional claims (Girija & Lakshman, 2011).

Furthermore, clinical studies have shown that *A. caudatus* seed provides cholesterol-lowering, hypoglycemic, antineoplastic activities, and stimulates the immune system (Caselato-Sousa & Amaya-Farfan, 2012).

### 5.3. Anti-diabetic activity

Some flavonoids, due to their phenolic structure, are involved in the healing process of free radical mediated diseases including diabetes (Czinner et al., 2000). The methanol extracts of this plant possess flavonoids as the anti-diabetic principles (Girija et al., 2011).

Methanol extracts of two amaranth varieties exhibited in vitro antidiabetic activity through the inhibition of the α-amylase enzyme (28%–50.5% at 25 μg/mL of concentration) streptozotocin (STZ)-induced diabetes rat model is characterized by a severe loss in body weight due to the degradation of structural proteins (Conforti et al., 2005). Treatment with methanol extracts of *A. caudatus* showed a significant fall in blood glucose levels and a significant gain in body weight was observed in the groups treated with methanol extracts (Girija et al., 2011). This may be due to the presence of 20% protein, all 8 essential amino acids, vitamins, calcium and minerals in methanol extracts to reduce hyperglycemia (Jain & Agrawal, 2003). It has been showed that *A. caudatus* stimulates insulin secretion in Goto-Kakizaki rats, a model of diabetes mellitus type 2 (Zambrana et al., 2018) as well as after four-week chronic daily dosing, different amaranth hydrolyzates inhibited the DPP-IV activity not only in vitro, but also in the STZ-induced diabetic mice (Jorge et al., 2015).

After three months of amaranth consumption, a seed containing bioactive peptides, some health improvements were observed in patients with diabetes and obesity (Barba de la Rosa et al., 2017).

Alpha-amylase is an enzyme found in the salivary, intestinal mucosal and pancreatic secretions. This enzyme increases the bioavailability of glucose in the blood. It has been reported that the inhibition of α-amylase reduces the bioavailability of glucose. *I*n-vitro studies demonstrate an appreciable α-amylase inhibitory activity with the methanol extract of A. caudatus L (Kumar et al., 2011).

Amaranth protein induces a decrease in plasma insulin in mice fed with a regular diet, whereas a decrease in triglycerides was observed in mice fed with high fat diet (Escobedo-Moratilla et al., 2017).

### 5.4. Antibacterial and antifungal properties

In plants, secondary metabolites function to attract beneficial and repel harmful organisms, serve as phytoprotectants and respond to environmental changes. In humans, however, the compounds have beneficial effects including antioxidant, anti-inflammatory effects, modulation of detoxification enzymes, stimulation of the immune system, modulation of steroid metabolism and antibacterial and antiviral effects (Lampe, 2003). Some results indicate that *A. caudatus* leave extract contained varied types of pharmacologically active compounds with antimicrobial activity (Maiyo et al., 2010).

Two antibacterial peptides named Ac-AMP1 and Ac-AMP2 were isolated from seeds of *A. caudatus*, demonstrating activity against different bacterial strains. These peptides also presented antifungal activity (Broekaert et al., 1992). Moreover, *A. caudatus* extract inhibits the invasion of *E. coli* into uroepithelial cells (Mohanty et al., 2018).

## 6. Conclusion

Several studies of unique nutritive value of both vegetable and *A. caudatus* seed rediscovered the plant as useful super crop of future keeping in view its minimum agronomic demand and food security of huge world population. The available literatures reveal that this underutilized crop has not received the attention that it deserves since *A. caudatus* has been reported for its anthelmintic, antinociceptive, antipyretic, anticancer, antiallergenic, antidiabetic, stimulation of the immune system, cardioprotective, hepatoprotective and antibacterial activities in relation to its antioxidant power. Most of these studies were concentrated on its nutritive value as human and animal feed, utilization of starch, basic biology, genetics and breeding practices. It needed a multidisciplinary research approach to enhanced *A. caudatus* as golden super crop of future.

## 7. Ethics statements

This study was conducted according to Good Clinical Practice Guidelines and in line with the principles outlined in the Helsinki Declaration of the World Medical Association.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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