Physicochemical Characteristics and Nutrient Composition of Three Grain Amaranth Species Grown in Hirna, Eastern Ethiopia

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Abstract: There is a growing interest in the cultivation of pseudo-cereals like amaranth and quinoa because of their nutritional merits for healthy food markets. In Ethiopia, domesticated cultivation of amaranth is limited (virtually non- existent). The aim of this research was to investigate the grain physicochemical characteristics of three different grain amaranth species (*Amaranthus caudatus*-red seed, *Amaranthus hypochondriacus*-white seed, and *Amaranthus cruentus*-black seed) collected from different parts of Ethiopia and cultivated in eastern part of Ethiopia. The percentage moisture, crude protein, crude fat, crude fiber, ash and carbohydrate contents were ranged from 10.4 to 11.3, 13.0 to 15.1, 7.0 to 7.5, 4.8 to 5.8, 2.1 to 3.4 and 57.3 to 58.5, respectively. The energy (k cal/100g), TKW (g), HLW (kg/hL) and grain size (diameter in mm) were ranged from 348.8-357.3, 0.4-0.5 g, 90.8-91.3 and 0.9-1.1, respectively. The amaranth grain species were rich in crude protein, fat and fiber as compared to common cereal grains (sorghum, tef, and rice) and are small in their grains size. The amaranths grain starch amylose studied were ranged from 13.5-35.4%. The grains Na, Ca, Cu, Fe, K, Mg and Zn contents (mg/100g) were ranged from 17.7-24.8, 73.4-175.6, 0.8-1.1, 17.5-32.5, 159.6-201.2, 74.2-123.5 and 2.8-3.5, respectively. There were significant difference ($p < 0.05$) on the mineral nutrient contents (Ca, Mg and K) among the three amaranth grain species. The amaranth grains can contribute significant Na, Cu, Fe, K, Mg and Zn to human nutrition. The high contents of protein, fat, fiber and mineral nutrients, balanced amino acids, the possibility of squalene a functional compound known to be associated with the amaranth fat contents justifies cultivation of amaranths in Ethiopia to contribute for food security. Studies to incorporate amaranths grains in different traditional Ethiopian foods for the production of nutritious and health supporting foods should be envisaged.

Keywords: Amaranth grain; Nutrient composition; Physicochemical properties

1. Introduction

Amaranths are herbs spread all over the world and are characterized by good adaptability in tropical conditions. It was cultivated by Aztecs since five to seven thousand years ago (Svirskis, 2003; Cai *et al*., 2004). Amaranth growing areas of the world spread from the south-west of USA, Africa, India, China through Central America and extend up to Argentina (Cai *et al*., 2004; Dhellot ., 2006).

Amaranth is easy to grow, nutrient rich and has the potential to contribute to the growing nutritional needs of a great majority of low income people because of its high protein content, superior protein quality, high contents of essential fatty acids and micronutrients (Venskutonis and Kraujalis, 2013). It has advantageous features like growing in marginal and infertile soils and adaptability to diverse agro-climatic conditions (Svirskis, 2003). The crop can well withstand drought heat and is hardly attacked by pests (Meyers, 1996; Cai *et al*., 2004 and Muyonga, 2008). Leaves of young amaranth plants are used as vegetable similar to spinach and lettuce in many Asiatic and African countries. Seeds (grains) of amaranth has a taste resembling that of nuts. Seeds are eaten boiled, roasted, crushed, or ground. It is used for porridge production, as well as in confectionery, pasta and candy production (Cai *et al*., 2004; Bruna, 2011). Amaranth is especially suited for mixing with other plant-derived flours (Meyers, 1996; Svirskis, 2003). Amaranth oil is used for the treatment of ontological diseases, sclerosis, malfunctions of the brain and periferic blood circulation system, immune deficient states, gynecological, skin, stomach and liver diseases, wounds, bruises, bedsores, ulcers, vitamin deficiency and for disease preventive purposes (Smith, 2000; Martirosyan ., 2005; Venskutonis and Kraujalis, 2013).

Chemical composition of most amaranth species was tested at the Novosibirsk Institute of Genetics and Cytology. Their collected seeds were reported to contain on an average 21% of crude protein of high protein heterogeneity and over 9% of crude fat (Svirskis, 2003). The leaves also contain high contents of protein, carotene, vitamins, and other valuable nutrients. The most valuable property of amaranth grains and leaves is that they contain high quality proteins and bioactive peptides (Simone, 2009; Berghofer and Schoenlechner, 2006; Quiroga *et al*., 2015). The content of lysine, the chief amino acid, in amaranth is 3.0 - 3.5 times higher than in maize, and 2.0 - 2.5 times higher than in wheat. Amaranth foods are especially suitable for people allergic to the wheat

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type gluten proteins. Amaranth seed contains about 7% of fat, which is used as raw material for the production of steroid preparations. Amaranth oil contains as much as 8% of squalene, a precursor for cholesterol and other steroids synthesis has shown to have anti-oxidant (Kim and Karadeniz, 2012; López-Mejía *et al*., 2014), tumor growth inhibition (Rao, 1998; Gregory and Kelly, 1999), skin protectant, ant-aging, detoxifier and anti-infectant effects (Kim and Karadeniz, 2012). Because of these squalene is widely used in the pharmaceutical drug delivery and skin care application (Reddy and Couvreur, 2009). Amaranth seed has been suggested as an alternative to marine animals as a natural source of squalene (He, 2002).

In Ethiopia, the amaranths plant is semi-domesticated on farm lands in Wollega, Konso and South Omo regions. Some farmers have started to cultivate and intercrop the species on their farm lands near their homesteads. The Konso people call amaranth *passa* and they also use its seeds for preparation of a local beverage known as '*Chaqa'*. The vernacular name of the plant varies from place to place in Ethiopia. It is also called *Lishalisho*, *Aluma* and *Ferenjitef* in Amharic; *Ambertefa*, *Iyaso* and *Jolili* in Oromo, and *Gagabsa* in Wolayita (Getahun, 1976; Emire and Arega, 2012)).

Considering the important nutritional and chemical composition of amaranth, introducing such a food crop provides an opportunity to fight major obstacles of human malnutrition and nutrient deficiency diseases especially in developing countries such as Ethiopia. However, there is no clear evidence on the various uses and types of amaranth as a source of nutrients and limited research has so far been done to elucidate the physicochemical characteristics of seeds of the plant in Ethiopia. Therefore, this study was conducted to determine the grain physical characters of amaranth (grain size, thousand kernel mass, and hectoliter weight, as well as the proximate chemical composition, concentration of essential elements (Ca, Mg, Na and K) and trace elements (Fe, Zn and Cu), and starch composition of common seed (grain) of some amaranth species grown in Ethiopia.

2. Methodology

2.1. Description of Source of Materials, Collection and Study Area

Seed samples of three amaranth species (*Amaranthus cruentus* L.-black seed, *Amaranthus hypochondriacus* L. –white seed and *Amaranthus caudatus* L.-red seed) were collected from different regions in Ethiopia based on the availability of plants and knowledge of the society regarding the use of the plant. Accordingly, three areas were selected, namely, East Wollega area (Jarte), West Wollega (Ganji), and Harar area (Harar town). Field experiments were conducted at Hirna Agriculture Research station of Haramaya University, which is located in western Hararghe in Ethiopia. The selected amaranth species were labeled, transported and authenticated at Haramaya University herbarium. The physicochemical analysis of the grains was conducted at Haramaya University.

2.2. Sample Preparation

Grains of the three species of amaranth were washed with tap water to remove dust particles and rinsed with deionized water. Then, the samples were air dried for seven days at room temperature (25^0C) and milled into fine flour using a sterile electric grinder (BLENDER 7012S, model HGB7WTS3, USA). The flour samples were stored at refrigeration temperature (5^0C) in an airtight container until used for analysis.

2.3. Cleaning of Apparatuses Used

Apparatuses such as glassware and plastic containers were washed with tap water using a detergent and rinsed with deionized water. The apparatuses were soaked in 10% (v/v) nitric acid for 24 h followed by rinsing with deionized water to remove acid. Then, the apparatus were dried in an air draft oven (50^0C) and kept in dust free place until analysis.

2.4. Chemical Analysis

2.4.1. Thousand kernel Weight

Thousand kernel weights (TKW) was determined on dockage free basis by measuring mass of 1000 kernels (AOAC, 2000). The TKW indicates grain size and provides information on grain filling nature and morphology.

2.4.2. Kernel Size

The kernel sizes (diameter, mm) were determined by digital caliper (model CD-6'P, Japan) as an average for 25 kernels.

2.5.3 Hectoliter Weight

The hectoliter weight (test weight) was measured on dockage free basis by measuring the mass of amaranth kernels contained in 500 mL and converting the result into kg/hL (Canadian Grain Commission, 2006).

2.5.4 Moisture Content

The moisture content was determined by drying about 3.0 g flour sample in an air-draft oven at 105°C for 3 h (AOAC, 2000, Method 925.10).

2.5.5 Ash Content

The ash content was determined by taking about 3 g of flour sample after carbonization and ashing at 550°C until light grey ash was obtained (AOAC, 2000 Method 923.03; Bultosa, 2007).

2.5.6 Crude Fiber Content

The crude fiber content was determined by taking about 2g flour sample as the portion of carbohydrate that resisted dilute sulfuric acid (1.25%) and dilute alkali (1.25%) digestions followed by subsequent sieving (75 microns), washing, drying, and ignition to subtract ash from fiber (AACC 2000, Method No 32-10).

2.5.7 Crude Fat Content

The crude fat content was determined by taking about 2.0 g sample flour by *Soxhlet* extraction (Model: EV 16, SN: 4002824, Germany) method using diethyl ether as a solvent (AACC, 2000, Method 30-20).

2.5.8 Crude Protein Content

The crude protein content was determined by *micro*-Kjeldahi method (Model UDK- 14, Europe) of nitrogen content analysis by taking approx. 0.2 g flour sample using urea as a control in the analysis (AOAC, 2000, Method No. 920-87). %Protein = %N x 6.25.

2.5.9 Carbohydrate Content

The total carbohydrate content was estimated by difference: 100 - (% Moisture +% Crude protein +% Crude fat +% Crude fiber +% Ash) (Monro and Burlingame, 1996).

2.5.10 Estimation of the Energy Value

Energy was calculated as described by Osborne and Voogt (1978) using the Atwater conversion factors:
E (kcal/100 g) = [9 * crude fat (%) + 4 * crude protein (%) + 4 * total carbohydrates (%)].

2.5.11 Amylose/Amylopectin Ratio

Amylose (%) was determined colorimetrically by iodine binding method (Charastil, 1987; Bultosa, 2007) by taking about 50 mg of flour samples. Normal maize starch (Merck UniLAB, code: 587 14 00) of 28% amylose content was used as a control in the analysis. Amylose (%) was determined from the standard (0-100% amylose of 10% variations) calibration curve. Data were evaluated on moisture, crude protein, crude fiber, crude fat and ash percentages free basis.

2.6. Mineral Nutrient Contents

The sample was ashed as described by Zeng (2004). About 1.0 g of flour sample was carbonized (200-250^{0}C, 30 min in preheated muffle furnace), dry ashed at 480^{0}C for 4 h, cooled, followed digestion with 2 mL of 5 M HNO_3 and then ashing was complete at 400^{0}C for 15 min. The ash was dissolved in 2 mL of concentrated HCl, evaporated to dryness on a sand bath, dissolved by 5 mL of 2 M HCl, filtered (Whatman No. 42 filter paper and <0.45 μm Millipore filter paper) and diluted with distilled water to 25 mL volumetric flask mark for mineral nutrient contents analysis.

The Ca, Mg, Fe, Zn and Cu contents were determined by atomic absorption spectrophotometer (BUCK Scientific, MODEL 210 VGB) method using air-acetylene as a source of energy for atomization and their respective hallow cathode lamps as light sources operated as recommended for the instrument (AACC, 2000). Parameters (burner and lamp alignment, slit width and wavelength adjustment) were optimized for maximum signal intensity of the instrument based on the mode of operation of the instrument. For Ca, content determination, absorbance was measured at 422.7nm after addition of 1% lanthanum (i.e., 1mL La solution/5mL) to sample and standard to suppress interferences. Calcium content was then estimated from standard solution (0.0-6.0μg Ca/mL) prepared from $CaCO_3$. For Mg, absorbance was measured at 285.2 nm and Mg content was estimated from standard solution (0.07-8.00μg Mg/mL) prepared from Mg metal ribbon. For Fe, absorbance was measured at 248.3nm and iron content was estimated from a standard calibration curve (0.01-6.00μg Fe/mL) prepared from analytical grade iron wire. For Zn, absorbance was measured at 213.8nm and zinc level was estimated from a standard calibration curve (0.02-4.0μg Zn/mL) prepared from ZnO. For Cu, absorbance was measured at 342.7nm and Cu content was estimated from a standard calibration curve (0.01-6.00μg Cu/mL) prepared from pure Cu metal. Sodium and potassium contents were determined by flame photometer as described in AOAC (2000) Method 956.01.

2.7. Data Analysis

A triplicate data were subjected to analysis. All analysis such as drawing of calibration curve, calculating mean, percentage were performed using Microsoft excel. Data were analyzed by one-way ANOVA for significant difference among the varieties and significance difference in means were considered at $p < 0.05$ using Fisher's least significant difference (LSD) test.

3. Results and Discussion

3.1. Amaranth Grains Proximate Compositions and Physical Character

With the exception of HLW, significant differences ($p < 0.05$) were observed among the three amaranth varieties in their moisture%, ash%, crude protein%, crude fiber%, total carbohydrate%, crude fat%, amylose%, energy value, TKW and kernel sizes (Table 1).

Moisture

The *amaranths* grain moisture contents were ranged from 10.4-11.3% (Table 1). The moisture contents were similar to the reported values of 11.3% by Caselato-Sousa and Amaya-Farf´an (2012) and 10.3% by Escudero *et al*. (2004), but slightly higher than 9.6% reported by Cai *et al.* (2004) and Emire and Arega (2012).

Ash

The ash contents were ranged from 2.1-3.4%. Similar ash contents (3.4%, 3.3%, 2.9% and 2.4%) were reported for amaranths grains by Escudero *et al*., (2004), Cai *et al*. (2004), Caselato-Sousa and Amaya-

Farf´an (2012) and Emire and Arega (2012), respectively. The ash contents of amaranths grains are comparable to the ash contents (2.7-3.0%) reported in grain tef (Bultosa, 2016). Ash content is an indicator of the mineral nutrient contents of the grain.

Crude protein

The crude protein content of *A. hypochondriacus* (15.1%) was highest when compared with *A. caudatus* (14.8%) and *A. cruentus* (13.0%). This result indicates that amaranth grain species contain more nitrogenous substances. Some of the earlier works also found that amaranth grain species are good sources of high quality proteins compared to the protein contents found in grains of common cereal crops (8 to 12%) (Koehler, and Wieser, 2013). Consistent with this study, amaranth grain protein contents were reported 16.6% (Cai *et al.*, 2004) and in other studies in the range of 12.5-17.6% in selected light-seed varieties (Venskutonis and Kraujalis, 2013) as particularly high nutritive value with high digestibility, and an amino acid composition close to optimal level for human nutrition. In addition to its complete amino acid profiles of high amount of lysine, amaranths grain proteins are implicated to have antitumoral, antihypertensive, antioxidant and hypocholesterolemic activities because of its bioactive peptides and this has encouraged for use of amaranths grains in various functional foods (Caselato-Sousa and Amaya-Farf´an, 2012; Quiroga *et al.*, 2015 and Sabbione *et al.*, 2015).

Crude fiber and total carbohydrate

The crude fiber content was ranged from 4.8-5.8%. The crude fiber content found were similar to the value 4.1% (Cai *et al.*, 2004) and 5.8% (Emire and Arega, 2012), but are lower than the total dietary fiber 9.8% and 6.7% reported by Escudero *et al.* (2004) and Caselato-Sousa and Amaya-Farf´an (2012), respectively. This is because the total dietary fiber takes into account both crude fiber and soluble fiber. The fiber content in amaranths are higher than common cereal grains: rice, maize, sorghum and wheat. The amaranths grains are good sources of dietary fiber for health food markets and are recommended to achieve hypocholesterolemic diet for peoples suffering from high cholesterol related disorders (Caselato-Sousa and Amaya-Farf´an, 2012).

The total carbohydrate content of the amaranths had ranged from 57.3-58.5% which is virtually starches. Amaranths grains are reported to contain about 60% starches (Caselato-Sousa and Amaya-Farf´an, 2012; Venskutonis and Kraujalis, 2013; Zhu, 2017) of small size granules (1 to 3 μm in diameter) with high digestibility resembling tef starch granules (2-6 μm in diameter) (Bultosa, 2016). This favor the use of amaranths grains as tef substitute in different food formulation.

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Table 1. Grain proximate composition, amylose content, energy value and physical characteristics of three grain amaranth species collected from different locations in Ethiopia.

Physicochemical properties	*A. hypochondriacus*	*A. caudatus*	*A. cruentus*	ANOVA p-values
Moisture (%)	10.4±0.0	11.2±0.0	11.3±0.0	0.0200
Ash (%)	2.1±0.0	2.4±0.0	3.4±0.0	0.0000
Protein (%)	15.1±0.1	14.8±0.1	13.0±0.1	0.0000
Crude fiber (%)	4.8±0.0	5.0±0.0	5.8±0.0	0.0000
Carbohydrate (%)	58.5±0.1	57.4±0.2	57.3±0.2	0.0012
Crude fat (%)	7.0±0.0	7.1±0.2	7.5±0.1	0.0000
Amylose (%)	24.0 ± 7.6	13.5± 2.2	35.4±1.6	0.0000
Energy (kcal/100g)	357.3±0.2	352.6±0.1	348.8±0.0	0.0000
TKW (g)	0.4±0.1	0.5±0.1	0.4±0.0	0.0002
HLW (kg/hL)	90.8±0.1	91.1±0.2	91.3±0.4	0.2215
Kernel size (mm)	1.0±0.0	1.1±0.0	0.9±0.0	0.0000

Note: TKW = thousand kernel weight, HLW = hectolitre weight, mm = millimetre, Amylose % found for control normal maize starch = 30.0± 8.3%.

Crude fat

The crude fat contents of the three amaranth grain varieties were ranged 7.0-7.5%. The fat content found was similar to the value 7.2% reported (Cai *et al.*, 2004). Others depending on species, fat content in amaranths grains were reported to range from 2 to 10% (Muyonga *et al.*, 2008; and Bressani, 1992; Caselato-Sousa and Amaya-Farf´an, 2012). Thus, the amaranths grains studied are regarded among the varieties characterized to be high in fat content. The high fat content may favor these varieties to bear high squalene level. Squalene in amaranth oil was reported to range from 2.4-8.0% of the ether extract (Reddy and Couvreur, 2009; Venskutonis and Kraujalis, 2013). Squalene is implicated to have different health supporting effects (anti-oxidant, tumor growth inhibition, skin protectant, ant-aging, detoxifier and anti-infectant) and is a precursor compound for cholesterol and other steroids synthesis (Caselato-Sousa and Amaya-Farf´an, 2012; Venskutonis and Kraujalis, 2013). The amaranths fat is predominantly an unsaturated fat (76%) and is high in palmitic, oleic and linoleic acids (Venskutonis and Kraujalis, 2013).

Amylose (%)

Starch is one of the major polysaccharides used by plants for energy storage and offers about 80% calories to human nutrition. Amylose/amylopectin ratio of starch granules are one fundamental property that will influence the end use characteristics of starches in foods and non-food industries. The amylose content of the amaranth grain species studied had varied widely (13.5-35.4%). The amylose % in *A. caudatus* are among low amylose bearing starches (semi-waxy type like in some rice starch granules), that of *A. hypochondriacus* are among those bear normal type starch granules (most normal cereal grain starch granules) and that of *A. cruentus* are among high amylo type starch granules (like legume starch granules). Similar to this finding, wide range 7.8-34.3% amylose were reported for different amaranth grains (Cai *et al*., 2004; Repo-Carrasco-Valencia and Arana, 2017). In other work, amylose % in the range of 4.7-12.5% was reported for different amaranth grains (Kong *et al*., 2009). There can be variation in the result of amylose% reported because of the differences in the analytical methods, sensitivities of the methods, species difference and sample nature used (i.e., analysis based on extracted starches or flour starches). There is also subtle amylose % variations by growing conditions even though the amylose % is genetically fixed. The wide difference observed in the amylose% found in this work suggest that such difference cannot be accounted to only analytical methods and sample nature differences. This calls further investigation to confirm the current result. Amylose % variation indicates the properties of starches such as swelling, gelatinization, pasting, gelling, retrogradation, freeze-thaw stabilities and digestibility can vary from each other.

Energy value

The energy values of different amaranth species were ranged from 348.9-357.3 kcal/100g. Calories variation among the varieties were at large contributed by the difference in their protein contents. The energy content found for the varieties are higher than 251 kcal/100g reported by Emire and Arega (2012) but are almost similar to the value 371 kcal/100g reported by Caselato-Sousa and Amaya-Farf´an (2012) on studies conducted on amaranths grains. The calories value found are higher than for tef grains (336 kcal/100g) (Bultosa, 2016) because amaranths grains contain high contents of proteins and fats than tef grains.

Thousand kernel weight (TKW), Hectoliter weights (HLW) and Kernel size

The amaranths grain species studied TKW were ranged from 0.4 to 0.5 g and the HLW from 90.8 to 91.3kg/hL. The kernel size (average diameter) were very small 0.9 to 1.0 mm. High HLW positively correlates with high starches in the kernel and may favor high malting potential for brewing (Nso, ., 2003). The TKW, HLW and grain size indicates that amaranth grains are classified among very light small size grains which can pack densely on storage with very small inter-granular air spaces. Such packing may contribute to the amaranth grains to be resistance to storage pest attacks.

3.2 Levels of Mineral Elements in the Amaranth Grains

There was no significant difference ($p < 0.05$) in the Na, Ca, F and Mg contents among the three amaranth grain species (Table 2). Whereas significant difference ($p < 0.05$) was observed in their Cu, K and Zn contents.

Table 2. Mineral nutrient contents of grain (mean ± sd) of three Ethiopian amaranth species

Mineral (mg/100g, db)	*A. hypochondriacus*	*A. caudatus*	*A. cruentus*	ANOVA p-values
Na	17.7±0.2	24.8±1.6	19.2±2.4	0.0048
Ca	73.4±13.2	110.7±9.8	175.6±4.7	0.0000
Cu	0.9±0.1	1.1±0.2	0.8±0.1	0.3235
Fe	17.5±4.3	25.0±4.3	32.5±4.3	0.0150
K	159.6±28.9	201.2±33.1	163.8±12.5	0.1839
Mg	74.2±1.5	109.9±15.8	123.5±5.2	0.0019
Zn	2.8±0.6	2.9±0.1	3.5±0.1	0.1360

Note: db=dry base, sd standard deviation

The results showed that the samples had variable mineral nutrient contents. Among the analyzed mineral elements, some were found to be high (K, Ca and Mg); Fe and Na contents were medium levels, and Zn and Cu contents were rather low.

Sodium

The Na content had ranged from 17.7 to 24.8 mg/100g which indicates amaranth grains are moderate in their sodium content but yet contains higher sodium content than found in cereal grains (Schakel *et al*., 2004). In other works, the sodium content of amaranth grain was reported to be 20 mg/100g (Schakel *et al*., 2004) and to range from 3.4-11.9 mg/100g (Dhellot *et al*., 2006). The recommended daily value for sodium intake varies with age and the current trend is toward reduction of sodium intake (1000 to 1500mg per day) because of high sodium intake link to hypertension (Otten *et al*., 2006; Horn, 2015). Sodium is essential element for appropriate maintenance of electrolyte balance, heart function, metabolic activities, muscle contraction and nerve transmission (Gharibzahedi and Jafari, 2017).

Calcium

The Ca content of the amaranth grains varied from 73.4 to 175.6 mg/100g. A typical value of 159 mg/100g (Caselato-Sousa and Amaya-Farf´an, 2012) and 153 mg/100g (Schakel *et al*., 2004) of Ca contents were reported for amaranth grains. Adequate Ca nutrition is important for bone and tooth structures development, muscle functioning, blood clotting and to reduce the incidence of osteoporosis (Gharibzahedi and Jafari, 2017). The recommended adequate Ca intake is between 210-1300 mg per day for different age groups (WHO, 2004; Otten *et al*., 2006). If assumed, the Ca in the amaranth grains are 100% bioavailable, the current amaranth grains can contribute in the range of 7.3% to 17.6% to the daily value for an individual whose daily Ca requirement is 1000 mg. However, factors like phytate, fiber and oxalic acid contents and vitamin D status of an individual limit the bioavailability of Ca.

Copper

The Cu content of the amaranth grains varied from 0.8 to 1.1 mg/100g. The Cu content found is similar to the typical Cu content (0.8 mg/100g) reported for amaranth grains elsewhere (Schakel *et al*., 2004). Although Cu is an essential element needed as co-factors in many enzymes, for proper functioning of organs, metabolic processes, for Fe and protein metabolism and to stimulate the immune system to fight infections, higher levels can be toxic to humans (Gharibzahedi and Jafari, 2017). Copper concentrations in plants range from 5 to 20 mg/kg (Midrar-ul-haq, 2005). Depending on age and physiological conditions, human requirements for Cu are in the range of 0.2 to 1.2 mg per day with upper tolerable Cu intake set at 10 mg per day (Collins and Klevay, 2011). The amaranth grains studied can contribute significant to the copper daily requirements but are far below the upper tolerable Cu intake level of 10 mg per day which can be exceeded if an individual can consume greater than 1 kg of amaranth grains per day. High levels of Cu may cause metal fumes fever with flue like symptoms, hair and skin discoloration, dermatitis, irritation of the upper respiratory tract, metallic taste in the mouth and nausea (Otten *et al*., 2006).

Iron

The Fe content in the amaranth grains had ranged from 17.5 to 32.5 mg/100g. The Fe content found is higher than the typical value (7.6 mg/100g) reported for amaranth grains (Schakel *et al*., 2004; Caselato-Sousa and Amaya-Farf´an, 2012) but are toward the higher range (3.6 to 22.5 mg/100g) reported by Kachiguma *et al*. (2015). The Fe content found in amaranth grains are almost similar to the Fe content reported in grain tef (Bultosa, 2016; Saini *et al*., 2016). The variation in the iron content in part is contributed by the agronomic factors difference from which the amaranth grains were harvested. The Fe dietary reference intakes requirement from age 1 to 50 years are in the range of 7 to 18 mg per day and during pregnancy is 27 mg per day (WHO, 2004; Otten *et al*., 2006). If assumed Fe is 100% bioavailable from amaranths grains, consumption of 100 g can almost meet the daily iron human nutrition requirements. However, because of Fe inhibitors like phytate, polyphenols (catechol, galloyl, condensed tannins and hydrolyseable tannins), fibers and calcium present in the plant based diets, Fe from plant food sources are only 5-10% bioavailable and thus amaranth grains consumption alone cannot meet the requirements (Saini *et al*., 2016). The Fe bioavailability may be enhanced by practices of fermentation known for example in grain tef *injera*. At a moment information on the mineral nutrient contents from amaranth grains traditionally fermented foods are limited and this calls further exploitation. Iron among others is required for formation of haemoglobin in red blood cells, which carries oxygen from the lungs to the body cells; for energy metabolism; for neuron signalling; as integrated part of important enzyme systems in various tissues and transport medium for electrons within cells (Saini *et al*., 2016). Iron is essential for proper brain functioning and development iron deficiency can cause anaemia and retarded mental development, which may be irreversible (Otten *et al*., 2006; Walker, 2007).

Potassium

The K content of the amaranth grains varied from 159.6 to 201.2 mg/100g. The K contents found were low as compared to the reported value of 508 mg/100g (Caselato-Sousa and Amaya-Farf´an, 2012), 366.7 mg/100g (Schakel *et al*., 2004) and 236.0 to 473.6 mg/100g (Kachiguma *et al*., 2015) for amaranth grains, which are also variable among themselves. Potassium is the main intracellular cation in the body and is required for normal cellular function (WHO, 2012). An adequate K intake are associated with reduced blood pressure, decreased risk of cardiovascular disease, increased bone-mineral density, and mitigation on the negative consequences of high sodium consumption. The WHO (2012) recommend potassium intake of at least 3510 mg per day for adults. Amaranth grains can contribute to the K human nutrition demand even though intake of amaranth grains alone cannot meet the requirements.

Magnesium

The Mg content of the amaranth grains studied varied from 74.2 to 123.5 mg/100g which is almost similar to the range 44.3 to 97.4 mg/100g (Kachiguma *et al.,* 2015), but appeared low as compared to 248.0 mg/100g (Caselato-Sousa and Amaya-Farf´an, 2012) and 266.7 mg/100g (Schakel *et al*., 2004) reported for amaranth grains. High amount of magnesium was recorded in *A. cruentus* and *A. caudatus*. Magnesium is involved in about 300 enzymatic processes as a cofactor, in the maintenance of intracellular levels of potassium and calcium, in the formation of protein, muscle contraction, immune system, maintenance of bone and other calcified tissues, nerve transmission and in assisting to avoid constipation (Otten *et al*., 2006). Magnesium deficiency are linked to hypocalcemia, muscle cramps, and seizures, as well as interference with vitamin D metabolism. Amaranth grains can contribute significant to adequate intake of Mg which for male and female age >18 years are 350 and 300 mg per day, respectively (EFSA NDA Panel, 2015).

Zinc

The Zn content of the amaranth grains studied varied from 2.8 to 3.5 mg/100g. The Zn content found was almost similar to the typical value 2.87 mg/100g (Caselato-Sousa and Amaya-Farf´an, 2012) and 3.20 mg/100g (Schakel *et al*., 2004), but appeared high as compared to the range 0.53-1.20 mg/100g reported by Kachiguma et al. (2015) for amaranth grains. The Zn content found in amaranth grains are almost similar to the Zn content (3.7 mg/100g) reported for grain tef (Schakel *et al*., 2004). Zinc is present in all body tissues and fluids, is crucial for growth and development. It facilitates several enzymatic processes related to the metabolism of protein, carbohydrates, fats and functions in the maintenance of the structural integrity of proteins and in the regulation of gene expression (WHO, 2004; Otten *et al*., 2006). Zinc deficiency in human results in a number of health problems, such as impairments in linear growth, sexual maturation, learning ability, immune functions and the central nervous system, susceptibility to infection, impaired wound healing (WHO, 2004). Zinc bioavailability in plant foods are low at large because of the presence of inhibitor phytic acid. In low bioavailable diet, for adult males (19-65 years), females (19-65 years), pregnant and lactating females, the recommended adequate daily intake for Zn were 14.0, 9.8, 11-20 and 14.4-19.0 mg (WHO, 2004). This shows consumption of amaranths grains can contribute to Zn requirements (i.e., 400 g amaranth grains) but because of Zn inhibitors, adequate Zn requirements cannot be satisfied by amaranths grain foods alone.

4. Conclusions

The main of this research was to investigate the grain physiochemical characteristics, amylose % and mineral nutrient contents of three different amaranth species (*A. caudatus*-red seed, *A. hypochondriacus*–white seed and *A. cruentus*-black seed) grown in Ethiopia. For the three amaranth grain species studied, significant differences were observed in their ash, crude protein, crude fiber, amylose, Na, Ca, Fe and Mg contents. The amaranth grains were rich in their crude protein, crude fiber and crude fat contents as compared to common cereal grains. The amaranth grains can contribute significant toward Na, Cu, Fe, K, Mg and Zn human nutrition requirements provided desirable foods with suppressed mineral nutrient inhibitors will be developed. The quantity of various nutrients found in the three amaranth grain species are ideal for human nutrition. Amaranths grains are also known for their high quality bioactive functional proteins with balanced amino acids, high oil that bears bioactive squalene and high dietary fiber which contribute to the development of healthful diets. These justifies the call for the cultivation of amaranths, research and development activities to develop desirable foods and beverages from amaranths grains that can be integrated into the traditional foods.

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