

# Effect of popping and fermentation on proximate composition, minerals and absorption inhibitors, and mineral bioavailability of *Amaranthus caudatus* grain cultivated in Ethiopia

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**Abstract** This study evaluated the effect of popping and fermentation on the chemical composition of three types of *Amaranthus caudatus* grains cultivated in Ethiopia. Proximate composition, minerals and mineral absorption inhibitors were analyzed. Popping caused a decrease in protein content by 4 % and an increase in fat, ash, acid detergent fiber (ADF) and neutral detergent fiber (NDF) contents by 12, 10, 15 and 67 %, respectively. While fermentation increased protein, fat and ash content by 3, 22 and 14 %, respectively but did not significantly change ADF and NDF content. Fe, Ca and phytic acid (IP6) decreased during popping but Mg, Zn, galloyl and catechol did not change significantly. On the other hand, fermentation increased Fe and Mg content but decreased IP6, galloyl and catechol content. The decrease in mineral absorption inhibitors especially IP6 during popping and fermentation could contribute to enhance mineral bioavailability. However, due to the presence of high phytate content in raw amaranth, all IP6-to-mineral molar ratios were above the recommended values.

**Keywords** *Amaranthus caudatus* · Popping · Fermentation · Proximate composition · Minerals · Phytic acid · Iron binding polyphenols

## Introduction

Amaranth is an ancient plant belonging to the family of Amaranthaceae which is believed to have originated from Central and South America (Gamel et al. 2006). It is a pseudocereal with high grain yield and capable of withstanding extreme climate and soil conditions (Capriles et al. 2008). Amaranth has good nutritional attributes with high level of protein, minerals, and fat as compared to the commonly utilized cereals such as barley, wheat, maize, sorghum (Mustafa et al. 2011; Pedersen et al. 1987). The high level of protein also presents a unique functional attributes such as high foaming and water absorption property of amaranth flour (Shevkani et al. 2014). Moreover, it has excellent amino acid profile with high amount of lysine and sulfur containing amino acids which are lacking in cereals and legumes, respectively (Amare et al. 2015). Amaranth oil is rich in unsaturated fatty acids and also contains a significant amount of squalene which can potentially prevent skin cancer and decrease serum cholesterol level (He et al. 2002).

The seeds of amaranth can be subjected to several treatments such as popping, toasting, cooking, roasting, flaking, extruding or grinding to be consumed as suspensions with water or milk or to be mixed with other cereal flours for bread and pasta making with improved quality (Capriles et al. 2008). However, its nutritive value is limited by the presence of high level of mineral absorption inhibitors especially phytates with a significant variations ranging between 0.52 and 2.24 g/100 g among different species studied so far (Lorenz and Wright 1984; Pedersen

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et al. 1987). According to Coulibaly et al. (2011) and Feil and Fossati (1997), growing conditions such as season, soil profile, harvesting techniques, stage of maturation, species and genotype are the main possible factors for the existing variations in phytate contents of crops. In line with this, some researchers also documented levels of other potential mineral absorption inhibitors such as tannins (Lorenz and Wright 1984; Mustafa et al. 2011) in different species of amaranth growing in different countries.

In Ethiopia amaranth can grow nearly all over the country yet the crop is underutilized in many parts of the country. In the Southern Nations Nationalities and Peoples (SNNP) region, especially in Bench Majji Zone, a particular ethnic group called Me'enit cultivates the crop and utilize it in different forms. The seed could be popped and milled to prepare thin porridge called "Atmit", thick porridge called "Genfo" or mixed with cold water to prepare an instant drink called "Besso" or fermented to prepare a drink called "Shamita/Borde". The raw seeds could also be milled, mixed with other cereal flours like maize and sorghum which then fermented for 3–4 and 48–72 h to prepare "Kita", unleavened bread and "Injera", a traditional pancake, respectively.

Although amaranth has a multiple food uses, limited information on its nutritive value and mineral absorption inhibitors of the crop grown under the agro ecological conditions of Ethiopia is available. Therefore, the aim of the present study was to determine the proximate composition, minerals and absorption inhibitors of three different types of *Amaranthus caudatus* grains cultivated in Ethiopia and evaluate the effect of popping and fermentation.

## Materials and methods

### Sample collection

Three different types of *A. caudatus* grains, white, red and brown in color, were purchased from six farmers living in Chat Kebelle, Bench Majji Zone, Southern Nations, Nationalities and Peoples region, Ethiopia in October 2011. Composite samples of each amaranth types prepared from the grains of the six origins were sorted, cleaned and washed to remove immature seeds, sand and soil. The washed seeds were sun dried and stored at 4 °C.

### Sample preparation

#### *Preparation of raw amaranth flour*

The composite samples for each type of amaranth grain were milled, sieved using 0.425 mm sieve and stored at 4 °C until further analysis.

### *Popping*

Cleaned and sun dried amaranth grains were popped as described in Amare et al. (2015). Briefly, the sun dried seeds were placed in a hot clay pan for 10–15 s until popping. The popped grains were then milled to pass through a 0.425 mm sieve and stored in polyethylene bags at 4 °C for further analysis.

### *Fermentation*

Natural fermentation was carried out according to the method described by Ibrahim et al. (2005) with modification. Briefly, 250 g of amaranth flour was mixed with 500 mL distilled water in a 600 mL beaker and then left to ferment for 48 h at room temperature ( $22 \pm 2$  °C). Thereafter, the sample was mixed with a glass rod and transferred to three aluminum dishes (30 cm diameter each) and dried in a hot oven (Heraeus UT 5042, Germany) at 50 °C for 20 h. The dried sample was then ground to pass a 0.425 mm screen and stored in polyethylene bags at 4 °C for further analysis.

### Proximate composition analysis

Crude protein content was determined according AOAC standard method 979.09 (AOAC 2000), where nitrogen content was determined by the Kjeldahl method and a conversion factor of 5.85 was considered as suggested by Berghofer and Schoenlechner (2002). The amount of crude fat was determined by the Soxhlet extraction according to AOAC standard method 920.39 (AOAC 2000). The ash content was determined after the removal of organic matter by dry ashing according to AOAC standard method 923.03 (AOAC 2000).

### *Neutral detergent fiber and Acid detergent fiber*

Neutral detergent fibre (NDF) content, which corresponds approximately to cellulose, hemicellulose and lignin content, and acid detergent fibre (ADF) content, which corresponds approximately to cellulose and lignin content, were determined according to the gravimetric method of Van Soest (1963) using a Fibertec 1020 (Foss, Hillerod, Denmark).

### *Determination of available carbohydrates*

Available carbohydrate was determined by difference and the result was expressed as g/100 g DM.

### Mineral analysis

The analysis of minerals was made by flame atomic absorption spectrophotometry (AAnalyst 800, Perkin

Elmer, France) following the method described in Hama et al. (2011) with modification. Briefly, about 0.4 g of sample flour was mixed with a mixture of 7 mL of concentrated nitric acid and 3 mL hydrogen peroxide and left to equilibrate for 30 min followed by digestion using microwave digester (Ethos-1, Milestone, Italy).

### Mineral absorption inhibitors

#### *Determination of phytic acid*

Myo-inositol hexaphosphate (IP6) content was determined by high-performance anion-exchange chromatography (Dionex, Sunnyvale, USA), after acid extraction, according to the method described in Hama et al. (2011). Briefly, 100 mg of the dried sample was extracted by using 5 mL of 0.5 M HCl in a boiling water bath for 6 min. The mixture was cooled in an ice bath and centrifuged at 4500 g for 20 min at 4 °C. The supernatant was filtered using 0.2 µm membrane filter before drying in a Speedvac (JOUAN, Saint Herblain, France). After drying, the sample was reconstituted with 2 mL of MilliQ water and injected into a high-performance anion-exchange chromatography using an AS-11 precolumn and column kit (Dionex, Sunnyvale, USA) for analysis with conductimetric detector. The HPLC conditions were: mobile phase 200 mM NaOH and HPLC grade water with gradient elution (15–40 % of 200 mM NaOH for 8 min, 40 % 200 mM NaOH for 1 min and 15 % 200 mM NaOH for 10 min), flow rate: 1 mL/min, column temperature: 30 °C, injection volume: 50 µL. Standard phytic acid solutions were also prepared from sodium phytate (Sigma) to develop a calibration curve. Results were expressed in gram per 100 g DM.

#### *Determination of iron binding polyphenols*

Iron-binding polyphenols (galloyl and catechol groups) were analyzed using the method of Brune et al. (1991). Briefly, to 50 mg of sample, 5 mL of 50 % dimethylformamide (Carlo Erba) in 0.1 N acetate buffer (pH 4.4) was added and the mixture was incubated for 16 h at 28 °C in a shaking water bath at 160 rpm. The solution was filtered using Whatman GF/A filter paper. From the supernatant, 0.5 mL was taken and mixed with 2 mL FAS (ferric ammonium sulfate) reagent containing 50 % urea (Merck) in 0.1 M acetate buffer (pH 4.4), 1 % gum arabic (sigma) and 5 % ferric ammonium sulfate (Riedel–de-Haen) in 1 M HCl. The mixture was incubated for 15 min at 30 °C and the absorbance of the colored complexes was measured at 680 and 578 nm, corresponding to the absorption maxima of Fe-galloyl and Fe-catechol complexes, respectively against a reagent blank consisting of 0.5 mL 50 % DMF and 2 mL of FAS-reagent. A food blank was also made by

mixing 0.5 mL of 50 % DMF and 2 mL of sample extract and the absorbance was subtracted. The concentration of galloyl groups (expressed as tannic acid equivalents) and catechol groups (expressed as catechin equivalents) were calculated from standard curves for catechin (sigma) and tannic acid (Merck) at the two wavelengths. All analysis were done in triplicate.

### Estimation of mineral bioavailability

#### *Molar ratios*

Molar ratios of phytic acid to minerals are the most frequently used method to estimate mineral bioavailability. The desirable molar ratios suggested for optimal absorption for adult diets are less than 1.0 or preferably less than 0.4 for phytic acid:iron (Hurrell 2004), less than 0.17 for phytic acid:calcium (Umata et al. 2005), and less than 15 for phytic acid:zinc (Gibson 2006).

### Quality assurance and quality control

In order to validate the accuracy of the analytical methods for protein, fat, ash and minerals three certified reference materials from the Institute for Reference Materials and Measurements (EU-IRMM), namely BCR-381 (rye flour), BCR-191 (brown bread) and BCR-679 (white cabbage) were used. The measurements were conducted based on the above procedure and the data was compared with the certified reference values (Table 1).

### Statistical analysis

Data were analyzed using two way analysis of variance (ANOVA) to determine significant differences among the processing methods using Statgraphics plus 5.1 (Statpoint, Warrenton, USA) software. Duncan multiple range test was used to compare the means.

## Results and discussion

### Proximate composition of raw amaranth grains

Table 2 shows the proximate composition of three types of *A. caudatus* grain. The protein and fat content of raw amaranth falls in the range of 14.0–15.5 and 7.5–7.7 g/100 g DM, respectively. The results were in agreement with previous reports by Kaur et al. (2010) and He et al. (2002). Fat content in amaranth grain was higher as compared to most conventional cereals such as wheat, maize and teff (Forsido et al. 2013). The available carbohydrate content of brown amaranth was lower than that of white

**Table 1** Quality assurance results for nutrient analysis of amaranth grain

Parameter	Units	Method of analysis	Reference material	Certified value	Analyzed values	Recovery (%)
Proximate						
Protein	g/100 g	Kjeldahl	BCR 381 (rye flour)	1.56 ± 0.01	1.48 ± 0.06	95
Fat		Soxhlet extraction		1.36 ± 0.16	1.25 ± 0.05	92
Ash		Ignition on muffle furnace		1.08 ± 0.11	1.09 ± 0.04	101
Mineral						
Iron	mg/100 g	Microwave digestion and flame AAS determination	BCR 191 (brown bread)	4.07 ± 0.23	3.90 ± 0.38	96
Zinc				1.95 ± 0.05	1.99 ± 0.04	102
Calcium				41.00	39.70 ± 0.82	97
Iron			BCR 679 (white cabbage)	7.97 ± 0.27	7.55 ± 0.18	95
Zinc				5.5 ± 0.25	5.72 ± 0.01	104
Calcium				776.8 ± 65.5	747.8 ± 1.2	96

**Table 2** Proximate composition of three types of raw *A. caudatus* grains

Grain type	DM (g/100 g DM)	Protein (g/100 g DM)	Fat (g/100 g DM)	Available carbohydrate (g/100 g DM)	Ash (g/100 g DM)	ADF (g/100 g DM)	NDF (g/100 g DM)
White amaranth	89.23 ± 0.10	13.88 ± 0.16	7.64 ± 0.05	68.41 ± 0.35	2.99 ± 0.08	5.49 ± 0.14	7.08 ± 0.36
Red amaranth	89.14 ± 0.09	15.15 ± 0.08	7.54 ± 0.06	67.15 ± 0.35	2.57 ± 0.02	5.99 ± 0.16	7.59 ± 0.41
Brown amaranth	88.88 ± 0.57	15.53 ± 0.24	7.72 ± 0.03	59.50 ± 1.98	3.10 ± 0.16	14.15 ± 1.89	14.79 ± 0.14

Values are mean of triplicates ±SD

DM dry matter, ADF acid detergent fiber, NDF neutral detergent fiber

and red colored amaranth grains (Table 2). This is associated with the high level of dietary fiber in brown amaranth as all the three types of amaranth contain comparable quantities of other nutrients.

The amount of ash in the three types of amaranth whole grains was in the range between 2.6 and 3.1 g/100 g DM, the maximum being for brown colored amaranth and the minimum for red colored amaranth. This was consistent with reports by Kaur et al. (2010). The content of acid detergent fiber (ADF), which corresponds to cellulose and lignin content, was the highest for brown amaranth (14.2 g/100 DM) followed by red (6.0 g/100 g DM) and white (5.5 g/100 g DM) (Table 2). Neutral detergent fiber (NDF) content was the highest in brown amaranth than other two types (Table 2). Pedersen et al. (1987) also demonstrated that colored amaranth have high amount of dietary fiber. The results of NDF in raw amaranth grains were also in agreement with the report by Mustafa et al. (2011) and higher than the amount of insoluble dietary fiber present in *Amaranthus hypochondriacus* reported by Czerwinski et al. (2004). The difference between ADF and NDF was comparable in white and red amaranth but lower in brown amaranth. This indicates that brown amaranth had lower

amount of hemicellulose, which is included during NDF determination, than the other types.

### Effect of popping and fermentation on proximate composition

The effect of popping and fermentation on the content of protein, fat, available carbohydrate (CHO), ash and dietary fiber (ADF and NDF) of three types of amaranth is shown in Table 3. Popping resulted in a significant decrease ( $p < 0.05$ ) in protein content from 14.9 to 14.3 g/100 g DM. The decrease in protein content might be attributed to the partial oxidation of heat labile amino acids. On the other hand, fermentation brought a significant increment in protein content. This is attributed to the loss of carbohydrates during fermentation (Svanberg and Lorri 1997). As the fermentation was spontaneous, i.e. without adding yeast or bacteria, no huge difference in protein was expected (Kazanas and Fields 1981). Fat content was significantly increased ( $p < 0.05$ ) from 7.6 to 8.5 and 9.2 g/100 g DM during popping and fermentation, respectively. The increase in fat content during fermentation could be due to the activation of yeast strains which could produce fat

**Table 3** Effect of processing on composition of the three types of *A. caudatus* grains

Treatment	Protein content (g/100 g DM)	Fat content (g/100 g DM)	Available carbohydrate (g/100 g DM)	Ash content (g/100 g DM)	ADF content (g/100 g DM)	NDF content (g/100 g DM)
Raw	14.9 ± 0.8b	7.6 ± 0.1c	65.0 ± 4.3a	2.9 ± 0.3b	8.8 ± 4.5b	9.6 ± 3.6b
Popped	14.3 ± 0.5c	8.5 ± 0.6b	57.9 ± 5.5c	3.2 ± 0.4a	10.1 ± 5.6a	16.2 ± 4.7a
Fermented	15.3 ± 0.9a	9.2 ± 0.2a	63.0 ± 4.8b	3.3 ± 0.6a	8.6 ± 4.6b	9.3 ± 3.5b

Values are means of nine measurements ±SD and means followed by different letters in the same column are significantly different at  $p < 0.05$  DM dry matter, ADF acid detergent fiber, NDF neutral detergent fiber

(Khetarpaul and Chauhan 1989). While the improvement observed after popping could be due to the partial removal of pericarp that was low in fat.

The ash content significantly ( $p < 0.05$ ) increased during popping and fermentation by 10 and 14 %, respectively. This may be associated with loss of dry matter allowing the minerals to concentrate (Svanberg and Lorri 1997). ADF and NDF content increased significantly after popping from 8.8 to 10.1 and 9.6 to 16.2 g/100 g DM ( $p < 0.05$ ), respectively. Ramulu and Rao (1997) also observed increased levels of insoluble dietary fiber during heat treatment of cereals. But the effect of fermentation on both ADF and NDF was not noticeable.

**Mineral contents of raw amaranth grains**

Total iron, calcium and magnesium content was the highest in brown colored amaranth (Table 4). Zinc content in the three types of amaranth was lower than that reported by Mustafa et al. (2011) and Nascimento et al. (2014). Fe content in raw grains showed variation ranging between 12.29 and 21.22 mg/100 g DM and the result was in agreement with the report by Mustafa et al. (2011) but higher than the report by Nascimento et al. (2014). Ca content also exhibited huge variation among the three types of amaranth (102–215 mg/100 g DM in raw samples). Brown amaranth showed the highest mineral contents, particularly Fe and Ca which were nearly twice of that measured in white and red amaranth. The result was not far from the reports by Pedersen et al. (1987) and Mustafa et al. (2011). Mg content ranged from 292 to 341 mg/100 g DM for raw grains. This was comparable with that reported by Mustafa et al. (2011) but higher than that reported by Nascimento et al. (2014).

**Table 4** Mineral content of three types of raw *A. caudatus* grains

Grain type	Fe (mg/100 g DM)	Zn (mg/100 g DM)	Ca (mg/100 g DM)	Mg (mg/100 g DM)
White amaranth	13.06 ± 1.79	3.40 ± 0.42	122 ± 2	292 ± 33
Red amaranth	12.29 ± 0.51	2.73 ± 0.08	102 ± 5	301 ± 10
Brown amaranth	21.15 ± 1.4	3.43 ± 0.21	215 ± 2	341 ± 8

Values are mean of triplicates ±SD

**Effect of popping and fermentation on mineral contents**

Popping significantly decreased ( $p < 0.05$ ) iron and calcium content (31 and 8 %, respectively). This decrease in Fe content could be attributed to the loss of pericarp during popping as more than 66 % of total minerals were found in the bran and germ fractions in amaranth (Berghofer and Schoenlechner 2002). On the other hand, no significant effect ( $p < 0.05$ ) was observed on Zn and Mg content due to popping (Table 5). It was concluded that the outer layer of amaranth grain contained high amount of Fe and Ca. On contrary, fermentation brought significant increase ( $p < 0.05$ ) in Fe and Mg but no significant change was observed in Zn and Ca (Table 5).

**Mineral absorption inhibitors**

Table 6 presents myo-inositol hexakisphosphate (IP6) content in raw amaranth grains. The amount was higher than that present in other cereals such as wheat, maize, buckwheat and rye (Egli et al. 2003). Such a high content of phytate probably strongly impairs the mineral bioavailability of amaranth based products and limits utilization of the crop to a wider consumer groups. In addition to phytate, polyphenols were also responsible for lowering mineral bioavailability (Brune et al. 1991; Khokhar and Owusu Apenten 2003). Therefore, polyphenols particularly iron binding polyphenols (galloyls and catechols) were measured in all raw amaranth grains and the result is shown in Table 6. Galloyl and catechol content was the highest for raw brown colored amaranth compared to raw red and raw white colored amaranth. Pigmented grains were known to have high amount of phenolic compounds (Manach et al.



**Table 5** Effect of processing on mineral content of three types of *A. caudatus* grains

Treatment	Fe (mg/100 g DM)	Zn (mg/100 g DM)	Ca (mg/100 g DM)	Mg (mg/100 g DM)
Raw	15.50 ± 4.4b	3.19 ± 0.4a	147 ± 52a	311 ± 28b
Popped	10.67 ± 0.78c	3.24 ± 0.4a	135 ± 46b	327 ± 32ab
Fermented	17.65 ± 4.9a	3.34 ± 0.5a	146 ± 51a	330 ± 20a

Values are mean of nine measurements ±SD and means followed by different letters in the same column are significantly different at  $p < 0.05$

**Table 6** Mineral absorption inhibitors in raw *A. caudatus* grains

Grain type	IP6 (g/100 g DM)	Galloyl (mg TAE/100 g DM)	Catechol (mg CE/100 g DM)
White amaranth	2.20 ± 0.15	93 ± 11	ND
Red amaranth	1.85 ± 0.25	100 ± 15	24 ± 16
Brown amaranth	2.09 ± 0.15	143 ± 10	54 ± 21

Values are mean of triplicates ±SD

ND not detected, IP6 *myo*-inositol hexakisphosphate

DM dry matter, TAE tannic acid equivalent, CE catechin equivalent

2004) and this was also confirmed by the results of total polyphenol in the three differently colored amaranth in this study (data not shown).

Substantial reduction in IP6 occurred during popping and fermentation by 39 and 77 %, respectively. This may be attributed to partial removal of pericarp during popping as phytates were known to be concentrated in the bran of most cereals (Hama et al. 2011). The impact of heat treatment (roasting and autoclaving) in reducing phytic acid content in chickpea cultivars has also been reported by Hussain et al. (1989). Repo-Carrasco-Valencia et al. (2009) also reported that extrusion cooking decreased the content of phytic acid in amaranth although not significant. The decrease during fermentation could be due to the activation of endogenous phytase or due to the action of exogenous phytase from fermentation microorganisms (yeast and lactic acid bacteria) when favorable pH was created (Baye et al. 2014).

Popping didn't exhibit a significant effect on the content of both galloyl and catechol. On the other hand, fermentation significantly decreased galloyl and catechol content (Table 7). This was in agreement with the reports of Mouquet-Rivier et al. (2008). An increased activity of polyphenol oxidase

might be the contributing factor to the polymerization of polyphenols making them less extractable.

#### Estimation of mineral bioavailability using molar ratio

The molar ratios of IP6:Fe for the three types of amaranth under different processing is shown in Fig. 1a. The result showed that IP6:Fe molar ratio was the highest for white amaranth followed by red and brown amaranth. The result also showed that popping and fermentation brought a marked decrease in IP6:Fe molar ratio. However, only fermentation in brown amaranth enabled to achieve the recommendation (IP6:Fe < 1). The fermented samples of the two other types should be consumed with mineral absorption enhancers in which case higher IP6:Fe molar ratio could be entertained to achieve better mineral bioavailability (Hurrell 2004).

The effect of popping and fermentation significantly reduced the molar ratios of IP6:Zn in all the three amaranth (Fig. 1b). However, fermented brown amaranth met the cut off level (IP6:Zn < 15). It has been observed that high levels of Ca exacerbate the inhibitory effect of phytic acid on Zn absorption in humans by forming a Ca–Zn–phytic

**Table 7** Effect of processing on mean mineral absorption inhibitors of three types of *A. caudatus* grain

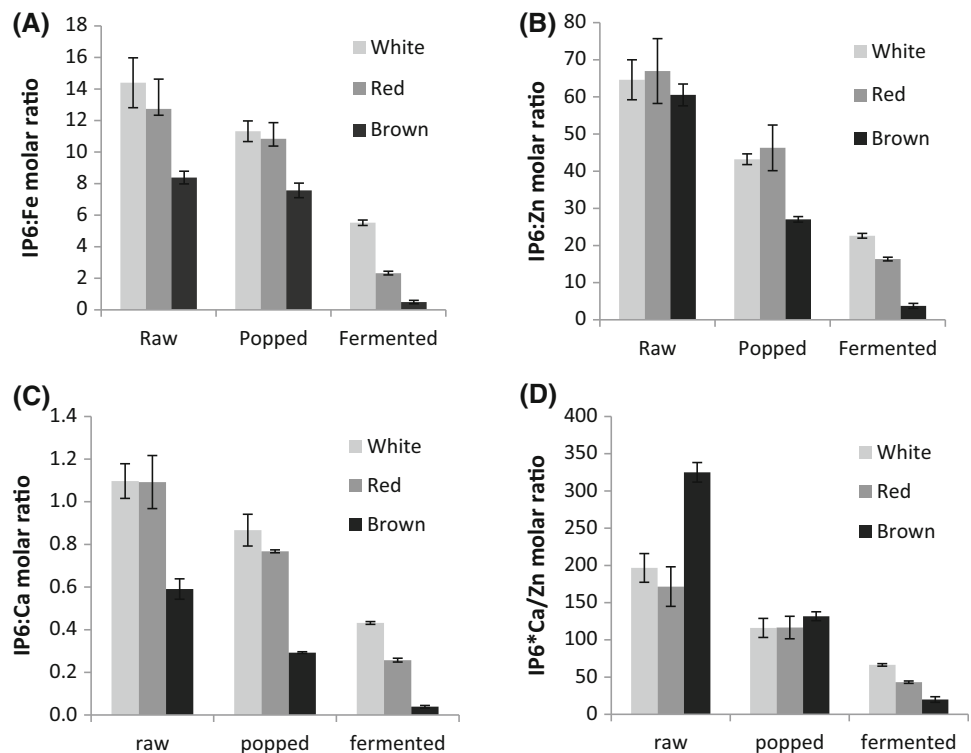
Treatment	IP6 (g/100 g DM)	Galloyl (mg TAE/100 g DM)	Catechol (mg CE/100 g DM)
Raw	2.05 ± 0.23c	112.00 ± 25.66b	26.11 ± 1.31b
Popped	1.25 ± 0.26b	104.56 ± 32.94b	24.78 ± 2.01b
Fermented	0.47 ± 0.31a	4.78 ± 22.06a	0.00 ± 0.00a

Values are mean of nine measurements ±SD and means followed by different letters in the same column are significantly different at  $p < 0.05$

IP6 *myo*-inositol hexakisphosphate

DM dry matter, TAE tannic acid equivalent, CE catechin equivalent

**Fig. 1** Effect of processing on molar ratios of IP6:Fe (a), IP6:Zn (b), IP6:Ca (c) and IP6 × Ca:Zn (d)



acid complex in the intestine, a more insoluble complex than phytate complexes formed in either ion alone (Fordyce et al. 1987). Thus the use of IP6 × Ca/Zn has been suggested as a better indicator of Zn bioavailability and if the value is above 200, the deleterious effect of Ca on Zn absorption is expected (Hemalatha et al. 2007). As seen in Fig. 1d, both popping and fermentation decreased the value of IP6 × Ca/Zn significantly and all, except the raw brown amaranth, had molar ratio above 200 due the relatively high amount of calcium in brown amaranth (Table 4). Similar effect was also observed on molar ratios of IP6:Ca where 21–51 and 61–93 % reduction was achieved during popping and fermentation, respectively. However, only fermented brown amaranth scored below the critical level (IP6:Ca < 0.17) (Fig. 1c).

In general, both processing methods (popping and fermentation) were effective in reducing the level of phytate to a greater extent. The effect of fermentation in reducing the content of phytic acid was far better than popping. However, due to the particularly high initial phytate content of amaranth, almost all IP6-to-mineral molar ratios were above the recommended values except for fermented brown amaranth. It is therefore necessary to design further strategies to maximize phytate degradation and improve mineral bioavailability.

## Conclusion

All the three types of amaranth cultivated in Ethiopia have been found to be rich source of protein and fat compared to most commonly consumed cereals in developing countries. These are also a good source of iron, zinc and calcium making them a potential crop for complementing both cereals and legumes. However, all the three types contained high amount of mineral absorption inhibitors mainly phytate that could significantly be reduced after popping or fermentation. Despite the attempt done to decrease the level of mineral absorption inhibitors using popping and fermentation, the level was high enough to bind minerals and consequently decrease bioavailability. It is therefore necessary to investigate further optional processing methods to fully exploit the crop to its nutritional potential. Furthermore, investigating the in vitro and/or in vivo bioavailability of key nutrients (iron, zinc and calcium) in those grain amaranth types and their interaction with anti-nutritional factors such as phytate, polyphenols and oxalate are also required.

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