IMPACT OF PROCESSING TECHNIQUES ON NUTRITIONAL COMPOSITION AND ANTI-NUTRIENT CONTENT OF GRAIN AMARANTH

J. W. Njoki, D. N. Sila and A. N. Onyango

Department of Food Science and Technology, Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya

E-mail: wanguijoycenj@ yahoo.com

Abstract

Grain amaranth (*Amaranthus albus*) is a pseudo cereal consumed in various parts of the world. It has attracted increasing interest over recent decades because of its nutritional and functional properties. Reducing anti-nutrients level in the grain prior to consumption increases nutrient utilization and absorption, and more so increases the bioavailability of nutrients. Therefore, this has lead to an advanced requirement to have advanced processing technologies to improve on bioavailability and utilization of nutrients Amaranth grain can be boiled, popped, roasted, or milled to make gruel for consumption. This study investigated the impact of dry and wet heat processing techniques on the nutrient and anti-nutrient contents of grain amaranth. Proximate composition, anti-nutrients content, protein digestibility and starch gelatinized were determined. The dry heating processes used included roasting and popping while the wet heating techniques included boiling whole grains and slurries. Generally, the effects of dry and moist heat processing with regards to loss and retention of the nutrients differed significantly ($p>0.05$), with only the roasting retaining more of the nutrients than boiled seed flour. Processing did not have significant effect ($p>0.05$) on proximate composition of grain amaranth. A pronounced reduction in the anti-nutrient content (tannins, oxalates, phytates) was observed in the case of boiling as compared to roasting and popping. Popping, boiling and slurring resulted in 78.0%, 86.2%, 92.6% increase in protein digestibility respectively whereas roasting reduced it to 66.3% as compared to raw grains (74.8%). Dry heating resulted in partial gelatinization of starch unlike wet processing which showed complete gelatinization. Therefore, processing techniques are required to reduce on the anti nutrient factors and promote utilization of nutrients by the consumer particularly the children, lactating mothers, HIV affected and infected, elderly and other people who may be at risk.

Key words: Grain amaranth, gelatinization, protein digestibility, anti-nutrient, chemical composition, processing techniques

1.0 Introduction

Amaranth is easy to grow, nutrient rich and underutilized pseudo cereal that can play an important role in actions against hunger and malnutrition that occur due to low rainfall conditions. Amaranths are broad-leafed non-grass plants that produce significant amounts of edible cereal-like grains. Amaranth (family Amaranthaceae) is an under-exploited plant with an exceptional nutritive value. A grain amaranth is very versatile as a food ingredient and can diversify farming enterprise; as it can be expected to prevent food depletion and to feed the world (Saunders and Becker 1984).

Amaranth grows rapidly and has a high tolerance to arid conditions and poor soils where traditional cereals cannot be grown. Amaranth has been touted as a miracle grain, a super grain, and the grain of the future (Samuel, 1991; Evgeny, 2001).Amaranth with an excellent seed quality and the greatest potential for use as a food ingredient is now grown as a grain crop in various parts of Kenya especially in Western region. Amaranth seeds with their phenomenal nutritional profile provide several important nutrients that are often difficult to incorporate into a restrictive diet.

The seeds contain large amounts of dietary fiber, iron, and calcium. The crude protein content of grain amaranth ranges from 11 to 17.6 % dry matter (Bressani *et al.*, 1987 a; Imeri *et al*., 1987 b; Bressani *et al.*, 1987 b). This is higher than in most common grains except soybeans. Grain amaranth complete protein contains around 5% lysine and 4% sulphur amino acids, which are the limiting amino acids in other grains. The lysine content is given as the main reason for the high protein quality of amaranth (Saunders *et al*., 1983; Teutonico and Knorr, 1985). Amaranth complete protein also contains significantly more sulphur amino acids than soya complete protein. The amino acid composition of amaranth protein compares well with the FAD/WHO protein standard. The high amounts of lysine, methionine and cysteine, combined to form a fine balance of amino acids, making them an excellent source of high quality, balanced protein, which is more complete than the protein found in most grains. In addition to its outstanding nutritional value, amaranth is also very low in sodium and contains less saturated fat (Garuda, 2004)

Amaranth meal, or flour, is especially suitable for where it can be used as a sole, or predominant, cereal ingredient. Grains can be roasted, popped, while whole grains can be boiled and mixed with various foods like rice, steamed vegetables and other dishes to boast nutrient level or be ground to produce flour which can be used to prepare gruel for consumption. The flour is used in Latin America and in the Himalayas to produce a variety of flat breads (tortillas and chapattis) (Teutonico and Knorr, 1985).

In Kenya, government and non-government organizations are currently working on the design and implementation of actions to mitigate hunger and malnutrition that affects vulnerable groups. In this context, the study of the different thermal processing techniques and their impact on their nutritional and anti-nutrient value of grain amaranth might contribute information about potential food sources and the best technique to be incorporated in the regional diets. It also imparts the relevance of value addition of these grains in the country.

2.0 Materials and Methods

2.1 Research Design

The seeds of grain amaranth (*Amaranthus albus*) were obtained from those cultivated on JKUAT farm. They were subjected to cleaning prior to storage for subsequent processing techniques and analyses.

2.2 Sample Preparation and Processing

Clean grains were subjected to different processing techniques. They were subjected to dry heat techniques (roasting 160^{0}C 10minutes and popping 190^{0}C 5s) and moist heat techniques (boiling whole grains 100^0 C 30min and slurring 100^{0}C 25 min). Effect of these processing techniques was determined by conducting nutritional and anti-nutritional composition of processed samples. For each treatment, three samples were analyzed each in triplicate.

2.3 Chemical Composition

Moisture content, ether extract and ash were determined using the AOAC methods (1995). The Zn, Fe, Cu, Ca and Mg content were determined by AAS, while Na and K were determined by FAS. Crude fiber (gravimetric) was determined based on the method outlined on AOAC (1995). Crude protein, N*6.25, was determined using the semi-micro kjedhal method as outline in AOAC (1995). Total carbohydrate content of the samples was determined by subtracting method (Pearson, 1976).

2.4 Anti-nutrient evaluation

Analysis of phytic acid in grain amaranth was done by HPLC combining the column/mobile phase conditions established by Tanjendjaja *et al.,* (1980), with modification as detailed by Camire and Clydesdale (1982***).*** Tannins were determined by the Folins- Denis colorimetric method described by Kirk and Sawyer (1998). The analysis of oxalates was determined according to Libert (1981) with modifications (Yu, *et al*., 2002).

2.5 Other Analysis

Protein digestibility was determined whereby pepsin digestion method was used based on that of Hamaker *et al.,* (1987). Degree of starch gelatinization was determined by light microscopy with iodine staining as **a**nalyzed using mastersizer 2000 produced by Malvern.

2.6 Data Analysis

Each determination was carried out on triplicates, on dry weight and wet weight basis and analyzed; the figures were then averaged using Microsoft Excel. Data were assessed using Analysis of Variance (ANOVA) with Genstat.

3.0 Results and Discussion

3.1 Chemical Composition of Raw and Processed Grain Amaranth

Table 1 shows the chemical composition of raw and processed grain amaranth. Results of raw grains and dry heat processed were reported in dry weight basis while moist heat (boiled and slurry) processed was reported in wet weight basis. Chemical composition of raw sample is slightly consistent with the reports presented by various researchers, who observed variations in the proximate composition of grain amaranth subjected to different processing methods. The chemical values obtained in this experiment are within the range reported in NRC (1994) table for heat-processed grains.

Moisture content of raw grains was slightly lower than the reported values (9.74 vs. 11-13%) (Table1). Processing has been outlined to have significant effect on moisture content of the final product. Dry heat decreased moisture content due to its loss during heat of the grains while moist heat increased it. In dry heat techniques; heat is transferred by convection to the food's surface, and then penetrates the food by conduction. The surface dehydrates, and the food browns from caramelisation. In moist heat techniques, this was attributed by hydration of grains and flour that lead to dilution of dry matter and thus increased moisture content of the grain and gruel.

Processing did not affect the concentration of crude protein, ether extract and ash significantly, but boiling lowered the concentration of crude protein. This is possible, due to leaching of nitrogen matter in the cooking water that was disposed prior to analysis.

The decrease in crude fibre content of the moist heated sample was attributed to loss of solid particles by boiling and slurring as compared to dry heat techniques (Albercht *et al*., 1966).

3.2 Mineral Composition

The result of mineral contents of raw and grain amaranth *A. albus* are shown in Table II. Moist heat and dry heat as processing methods decreased the calcium, magnesium, iron contents. In effect, the calcium (Ca) magnesium (Mg) zinc (Zn) copper (Cu) sodium (Na) potassium (K) and iron (Fe) contents of the raw *A. albus* seed flour were significantly better ($p>0.05$) than the minerals contents of the processed samples, respectively. The calcium contents decreased from 578.25 mg/100mg (raw) to 374.75 mg/100g (boiled) 318.87mg/100g (Slurried)and 545.15 mg/100g (roasted) 562.53mg/100g (popped) while, that of magnesium also decreased from 653.27 mg/100g (raw) to 473.74 mg/100g (boiled), 326.78mg/100g (Slurried) 546.45mg/100g (roasted) and 578.49mg/100g (popped). Although, both moist and dry heat decreased the sodium and potassium contents of the raw *A. albus*, there was no significant difference ($p<0.05$) between the raw and processed samples. Sodium content in raw *A. albus* seed flour decreased from 94.54 mg/100g (raw) to 69.68 mg/100g (boiled), 65.43mg/100g (Slurried), 87.96 mg/100g (roasted) and 90.86 mg/100g while, potassium decreased from 729.7 mg/100g (raw) to 620.5 mg/100g (boiled), 604.86 mg/100g (Slurried), 709.1 mg/100g (roasted) and 715 mg/100g (popped).

Comparatively, it has been observed that moist heat techniques decreased the mineral content more than the dry heat method. This occurred probably because soluble minerals leached into the processing water with long cooking time. This result agreed with the research of Fox and Cameron (1984) and Edem *et al*. (1994) that soluble minerals get lost by dissolving into cooking water

3.3 Anti-nutritional Factors

The effect of different thermal processing methods on the levels of anti-nutritional factors has been shown in Figure I. All the thermal processing methods reduced tannins, phytates and oxalates. However, the reduction of anti-nutrients was highest with moist heat (91 to 57.7 mg/100g for oxalates, 0.304 to 0.206mg/100g for tannins). The reduction concentrations for popped and roasted grain amaranth were almost similar.

Thermal processing of grain amaranth is acknowledged to be very successful in enhancing the nutritional value of grain amaranth and in reducing these anti-nutrient factors. These processes are however affected by many and varied reports on the influence temperature-time combinations on the anti-nutrient factors. Oxalates and tannins may be removed from food by cooking in water, although this is not the most effective method. Soaking followed by wet cooking may reduce oxalates more rapidly when compared with just wet cooking.

Roasting was found to be the least effective method of reducing these anti-nutrients contents. The roasting of grain amaranth decreased the oxalate content by 56.1%. Around 80.9 % total oxalates were lost when grain amaranth were Slurried compared with being boiled (69%) and popped (66.4%). Although moist heat processing proved most effective in terms of the reduction of total oxalates, chances of losing other water-soluble nutrients was, possible minerals also leached out at the same time.

As it has been shown on Fig I, raw grains had the phytates content amounting to around 0.796mg/100g, roasting; popping, boiling and slurring had 0.792, 0758, 0.301 and 0.201 mg/100g respectively. The phytates content of the raw grain is in the range that has been reported. Whittaker and Ologunde (1990) reported that phytate content in raw amaranth cereal is 7.92 mg/g. Ruiz and Bressani (1990) reported the phytic acid content in amaranth crentus grain as 0.29%. Matz (1991) reported that the phytates content in different grain amaranth was in the range of 0.3-0.6%. Generally, all the processing techniques reduced the phytates contents in grain amaranth. Roasting and popping had slight reduction of phytates content, while boiling and slurring ha great reduction of phytates. From the table it has been clearly shown that moist heat processing had greater impact in reduction of phytates concentrations as compared to dry heat techniques.

3.4 Protein Digestibility

Data in Figure II indicates that protein digestibility of raw and processed grain amaranth. The protein digestibility of this grain variety obtained from JKUAT farm was found to be around 74.8%. Dry heat (popping) and moist heat (boiling and slurring) improved protein digestibility (78.04%, 86.19% and 92.55%) respectively but roasting which is commonly used in major grain preparation methods, was found to reduce digestibility to 66.32%.

It has been reported that the true digestibility of the raw complete amaranth protein is in the range 74 - 80 % which is in the range of obtained value. However, the digestibility and the protein efficiency ratio are significantly improved if the grain is heat processed (Garcia *et al*., 1987). At the heat treatment, trypsin inhibitors and other anti-nutritional substances are denatured (Imeri *et al*., 1987). The relatively low protein digestibility of raw grain amaranth may be attributed to the influence of anti-nutrients such as enzyme inhibitors, lectins, phytates, tannins and dietary fiber, which inhibits protein digestion, and also due to presence of protein structures that resist digestion.

The digestibility of popped is higher than in raw grain, but lower than in wet cooked grain and gruel. This is probably due to unfolding of the proteins during protein denaturation, thus exposed more proteins for enzyme digestion, also there was reduction of anti-nutrient factors that mostly inhibit digestion of proteins by enzymes. Roasting was the least technique that reduced the protein digestibility, and even scored less than raw grains. This could have been attributed by prolonged period of heating of grains during roasting; that lead to maillard reaction and hence rendered most proteins unavailable for digestion.

It has been shown that wet cooking improved the protein quality the most as compared to dry cooking. The level of anti-nutrients is also known to reduce protein digestibility of cereal grains. The slurry had the highest protein digestibility as compared to all processing techniques; this is because there is size reduction of grains attributed by milling to flour thus increasing surface area exposed for enzyme digestion. Popping and moist heat processing may have contributed to denaturation of proteins. This exposed most of the proteins for enzyme digestion in relation to roasting.

3.5 Starch Gelatinization

By light microscopy, the granules of raw grain amaranth showed polygonal shape (Figure I), whereas dry heat shown some loss of cavities (Figure II and Figure III) and moist heat showed great irregularity of cavities (Figure IV and Figure V) which resulted from imbibitions of water that lead to swelling, disruption of starch granule that lead to collapse of these granules.

Changes in starch during processing have been extensively studied for human food applications (Hellendoorn *et al*., 1975).Most starches will gelatinize upon heating to above 80^0C in excess water. Gelatinization markedly increases susceptibility for amylolytic degradation due to loss of crystalline structure. Gelatinization has been described as a swelling driven process. Swelling occurs along the amorphous regions, and since the crystalline regions do not expand during swelling, stress increases at the interface between the crystalline and amorphous regions, where bonds exist between amylopectin in the crystalline regions and amylose in the amorphous regions. Thus, at a certain point in the swelling process, the crystalline regions are rapidly and irreversibly broken and gelatinization is initiated (Fennema, 1996).

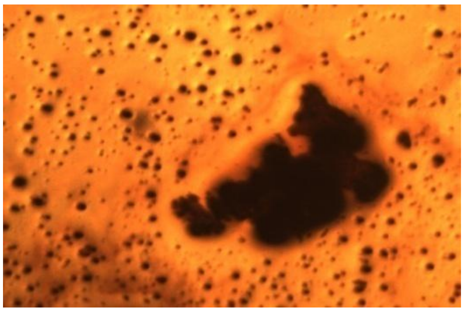


Figure I: Raw grain

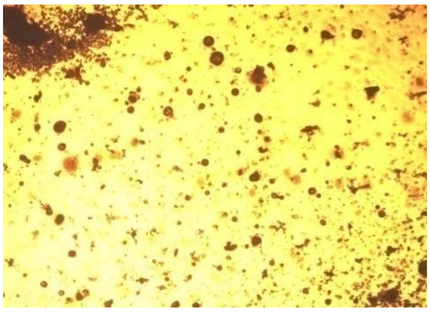


Figure II: Roasted grains

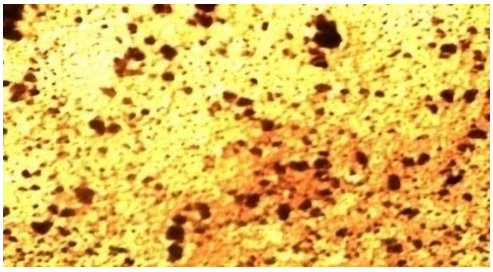


Figure III: Popped grains

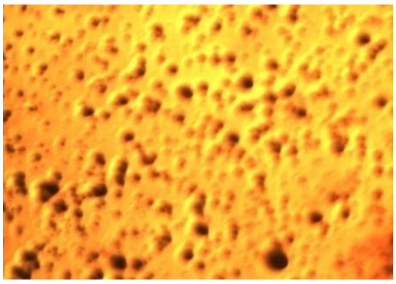


Figure IV: Boiled grains

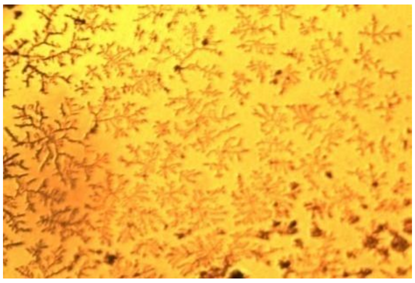


Figure V: Slurried sample

Moist heat (boiling and slurring) causes the starch grains to swell so that the coating of cellulose is broken and softened. After being softened and swollen, the starch granules become gelatinized. This may take place below -the boiling point but most starches in various cereals are more thoroughly cooked by high temperatures. Raw starches cause much digestive trouble. Cook all starches thoroughly. At excess water content, this onset of the gelatinization usually occurs between 50 and 70^{0}C. Swelling causes nearly all amylose in the starch granule to leach out.

Viscosity increases during gelatinization, and is caused by swollen granules and gels consisting of solubilized amylose). In addition to the importance for starch digestion, the increase in viscosity during gelatinization may also affect physical quality of processed feeds positively through increased binding between feed particles. Boiling and slurring are moist-heat-cooking method that uses the process of convection to transfer heat from a liquid to a food. They use large amounts of rapidly bubbling liquid to cook foods. The turbulent waters and the relatively high temperatures cook foods
Dry heat (popping and roasting) changes starch to dextrin, a form of sugar that is very soluble. Popping is achieved by rapid, intense heating of grain; it makes water expand all at once; thereby expanding the grain. As expansion takes place, some of the granules are gelatinized resulting in the grain being much more available to digestive enzymes. In roasting, water is lost without the expansion of the grain; this is because grains are heated at a much slower rate than the popping. This results to partial gelatinization of starch. This change takes place in the crust of bread, and for this reason, the crust is more digestible than the center portion of a loaf.
During dry heat, there is partial breakdown of starch that lead to formation of dextrin .On heating dextrin polymerise to form longer chains, and become brown coloured substances called pyrodextrins**.** Pyrodextrins

contribute to the brown colour and the characteristic taste and texture of many foods including toast and bread crust.

4.0 Conclusion

According to the study, grain amaranth has shown to be a good supplier of nutrients particularly high protein which is in minimal amounts in other cereals like maize, wheat and other legumes except soybeans. Dry and moist heat as processing methods reduced the anti-nutrients content, but moist heat was more effective in their reduction of anti-nutrients when compared with the dry heated samples. It was also observed from the result that processing of grain amaranth by dry heat (popping) and moist heat reduced anti-nutrients and improved on digestible and starch gelatinized which enhanced better utilization of these grains when processed.

Acknowledgements

I wish to express my sincere gratitude and appreciation to Australian Government (AusAID) through, A BecA hub-CSIRO initiative on Food and Nutrition Security for sponsoring and enabling the completion of this research work at Jomo Kenyatta University of Agriculture and Technology.

Reference

Association of official agricultural Chemists (1995) official methods of analysis of the AOAC, I5th ed Arlington, Virginia: Association of Official Analytical Chemists.

Fox, B. A. and Cameron, G. A. (1984). Food Science: A Chemical Approach, Holder and Stouton. London.

Bressani, R., Elías, L. G., González, J. M., Gómez-Brenes, R., (1987a). *Arch Latinoam Nutr.,* **37**: pp 364-377.

Bressani, R., González, J. M., Zúñiga, J., Breuner, M., Elías, L.G., (1987b). *J Sci Food Agric.,* **38**: pp 347-356.

Saunders, R. M. and Becker, R., (1983). **In**: Pomeranz Y. (ed.) Advances in cereal science and technology, Vol. 6. St. Paul, Minn, USA: American Association of Cereal Chemistry, 1983.

Teutonico, R. A. and Knorr, D., (1985). *Food Technol.,* **39**: pp 44-00.

Garcia, L. A., Alfaro, M. A. and Bressani, R., (1987). *J. Agric. Food Chem*. **35**: pp 604-607.

Imeri, A., Florez, R., Elias, L. G. and Bressani, R., (1987a). Arch. *Latinoam. Nutr.,* **37**: pp 160-173.

Yánez, E.; Zacarías, I.; Granger, D.; Vásquez, M.; Estévez, A. M. (1994). Chemical and nutritional characterization of amaranthus (Amaranthus cruentus)] *Arch. Latinoam. Nutr.*, **44**, 57-62.

Camire, A. L and M, Clydesdale, M. (1982). Analysis of Phytic acids in Fooods by HPLC. *J Food Sci.*, **47**, pp 576.

Colmenares de Ruiz and Bressani, R. (1990). Effect of Germination on the Chemical Composition and Nutritive Value of Amaranth Grain. Cereal Chemistry 67.

Whittaker, P and Ologunde, M. O. (1990). Study of Iron Bioavailability in a Native Grain Amaranth Cereal for Young Children using a rat model. *Cereal Chem.,* **67**(5): pp 505-508.

Samuel A. Matz, (1991). Chemistry and Technology of Cereals as Foood & Feed.

Grubben G. J. H. (2004). Plant Resources of Tropical Africa: Vegetable.

Peter, S. B. and John R. N. T., (2002). Pseudocereals and Less Common Cereals: Grain Properties and Utilization.

Table 1: Chemical composition of raw and processed grain amaranth (mg/100g)

Parameters	Moisture content	Crude protein	Crude fat	Crude ash	Crude fiber	CHO
Raw grain	9.74±0.17	14.44±0.15	7.09±0.13	3.18±0.13	4.27±0.13	66.28
Popped grain	6.38±0.08	14.15±0.14	6.87±0.14	3.07±0.05	3.36±0.09	65.17
Roasted grain	5.78±0.15	14.15±0.14	7.00±0.14	2.88±0.12	4.09±0.17	64.95
Boiled grain	73.99±0.09	3.53±0.08	1.69±0.06	1.32±0.06	2.09±0.21	17.38
Slurry	86.37±0.04	2.81±0.13	1.34±0.2	0.88±0.05	1.57±0.1	7.03

Table 2: The mineral composition of raw and processed sample of grain amaranth (mg/100g)

parameters	Raw grain	Popped grains	Roasted grains	Boiled grains	slurry
Fe	35.02±0.09	23.90±0.1	18.12±0.2	15.50±0.12	7.26±0.06
Mg	653.27±0.12	578.49± 0.10	546.44±0.03	473.73±0.17	326.78±0.14
Ca	578.24±0.01	562.53±0.09	545.15±0.06	374.75±0.13	318.86±0.09
Zn	5.33±0.13	5.151±0.02	3.61±0.07	1.79±0.02	1.35±0.04
Cu	0.916±0.12	0.83±0.017	0.81±0.12	0.46±0.07	0.40±0.06
K	729.69±0.02	714.98±0.07	720.54±0.04	620.54± 0.05	604.86± 0.03
Na	94.537±0.11	90.861±0.02	87.96±0.03	69.67±0.08	65.42±0.07

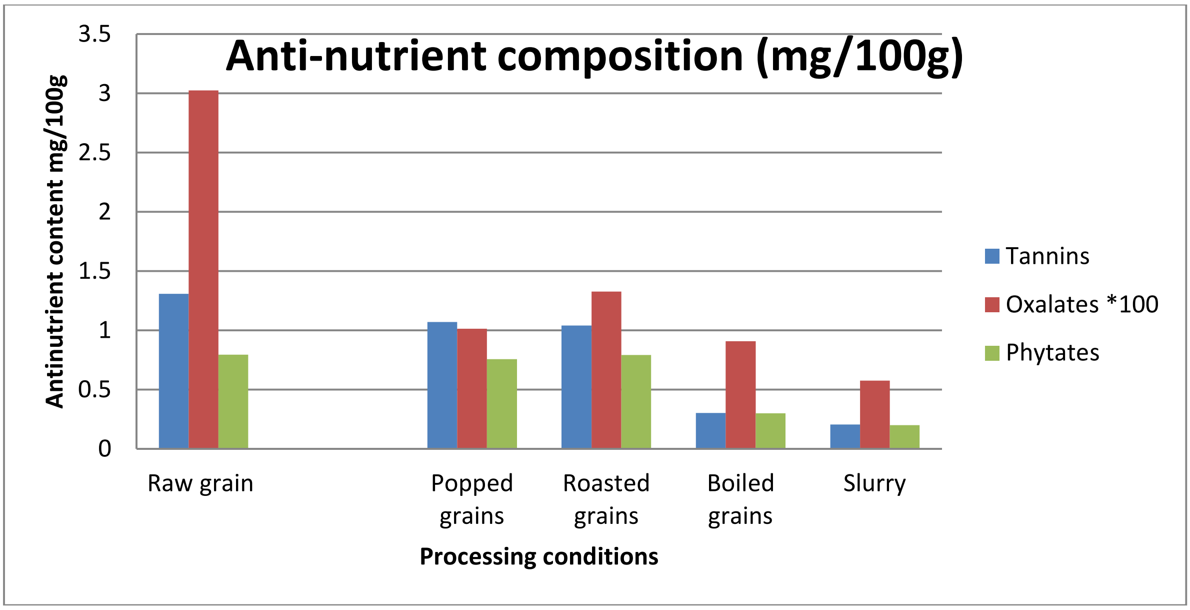
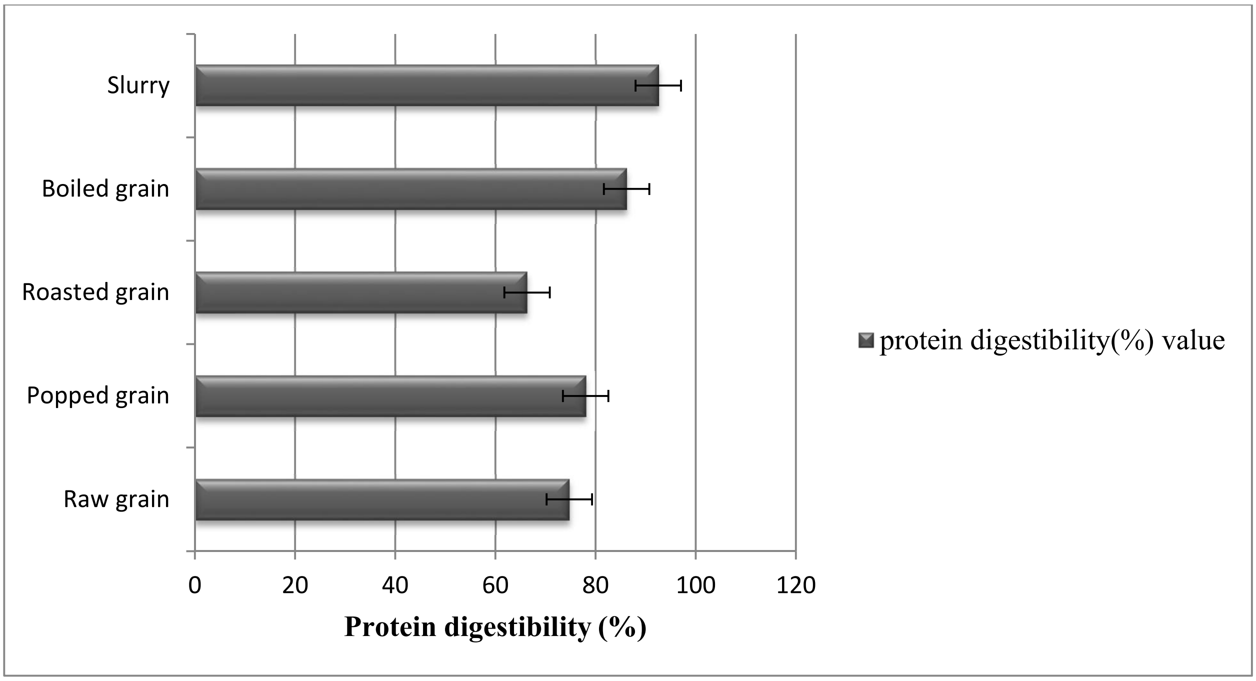


Figure 1: Anti-nutrient contents of grain amaranth (mg/100g)


Slurry
Boiled grain
Roasted grain
Popped grain
Raw grain
0
20
40
60
80
100
120
Protein digestibility (%)
protein digestibility(%) value