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Study on nutritional quality and health benefits of the under-utilized pseudo-cereal golden amaranth seeds in Tanzania

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Abstract

This research seeks to evaluate the nutritional quality and health advantages of amaranth seeds, a pseudo cereal that remains largely unexplored in Tanzania. Evidence indicates that amaranth seeds are abundant in both macro and micronutrients. The seeds exhibit a high dry matter content ($91.82 \pm 0.01\%$), along with notable levels of protein ($18.98 \pm 0.13\%$), crude oil ($8.25 \pm 0.95\%$), crude fibre ($5.55 \pm 0.25\%$), and total carbohydrates ($65.27 \pm 0.45\%$). Additionally, they provide a total energy value of 359.71 ± 2.25 Kcal per 100 grams, with an ash content of $3.05 \pm 0.12\%$, ascorbic acid at 4.69 ± 0.02 mg per 100 grams, and β -carotene at 2.67 ± 0.08 mg. The mineral composition includes iron (69.24 mg/100 g), zinc (12.31 mg/100 g), calcium (182.21 mg/100 g), magnesium (292.15 mg/100 g), manganese (6.03 mg/100 g), and potassium (407.13 mg/100 g). Furthermore, the seeds are rich in essential amino acids, including lysine (7.89 ± 0.17 g/100 g), leucine (6.39 ± 0.03 g/100 g), aspartic acid (10.87 ± 0.16 g/100 g), and glutamic acid (17.34 ± 0.16 g/100 g). Amaranth seeds also offer numerous health benefits, such as enhancing bone health, promoting gut health, and exhibiting anti-inflammatory, anti-hepatitis, anti-obesity, and anti-diabetic properties, thereby aiding in the prevention of various diseases. Despite their potential, amaranth seeds are underutilized in developing nations. The findings of this study advocate for increased incorporation of these seeds into food products aimed at addressing macro and micronutrient deficiencies, as well as combating non-communicable diseases in these regions.

Keywords: Pseudo cereal, golden amaranth seeds, amino acids, minerals

Introduction

Cereals, belonging to the Poaceae family, which is a group of monocotyledonous grasses, include varieties such as wheat, rice, maize, sorghum, millet, barley, and rye. The starches derived from these grains serve as a significant food source (Sarwar *et al.*, 2013) [36]. Various food items and products produced from cereals encompass flour, pasta, cakes, porridge, pancakes, chapati, halva, starches, ready-to-eat weaning mixes, breakfast cereals, breads, popcorn, bulgur, quinoa, couscous, and oatmeal. Whole-grain foods, including whole-grain bread, brown rice, and whole-grain pasta, can also be utilized in food production. For instance, whole grains have been shown to help regulate hypoglycemia, making them a recommended choice for individuals with type 2 diabetes to maintain normoglycemia (Chuwa *et al.*, 2021) [16]. Cereals provide essential carbohydrates (found in meat, wheat, and corn), proteins (from legumes and pulses), fats (such as those in peanuts, sesame, pumpkin, soybeans, pistachios, almonds, walnuts, and sunflower seeds), and minerals (present in pearl millet, sorghum, millet, barley, and rye). While some foods are nutritious, others, particularly small grains and quinoa, offer both nutritious and easily digestible nutrients (Rodriguez *et al.*, 2020) [35]. This advantageous food source is characterized by a rich combination of nutrients and high bioavailability.

Pseudocereals, in contrast to traditional cereals, are classified as seeds or fruits. Products derived from cereals encompass a wide range of items, including flour, pasta, cakes, porridge, hard porridge, pancakes, chapati, halva, starches, ready-to-eat weaning mixes, breakfast cereals, breads, popcorn, bulgur, quinoa, couscous, and oatmeal. Whole grain foods, such as whole grain bread, brown rice, whole grain pasta, and maize, can also be utilized in food production.

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For instance, whole foods are recommended for individuals with type 2 diabetes to help regulate blood sugar levels (Chuwa *et al.*, 2021) ^[16]. Cereals provide essential carbohydrates (from sources like meat, wheat, and corn), proteins (from legumes and pulses), fats (from peanuts, sesame, pumpkin, soybeans, pistachios, almonds, walnuts, and sunflower seeds), and minerals (found in pearl millet and sorghum). While some foods are nutritious, others, particularly small grains and quinoa, offer digestible nutrients (Rodriguez *et al.*, 2020) ^[35]. This advantageous food source is characterized by a rich nutrient profile and high bioavailability. Pseudocereals, distinct from cereals, are defined as seeds or fruits from members of the Poaceae family, which includes grasses such as wheat, rice, maize, sorghum, millet, barley, and rye. The starches derived from these plants serve as a significant food source (Sarwar *et al.*, 2013) ^[36].

Foods and products derived from cereals encompass a variety of items such as flour, pasta, cakes, porridge, hard porridge, pancakes, chapati, halva, starches, ready-to-eat weaning mixes, breakfast cereals, breads, popcorn, bulgur, quinoa, couscous, and oatmeal. Whole grain foods, including whole grain bread, brown rice, whole grain pasta, and maize, can be utilized in food production. For instance, whole grains are known to help manage hypoglycemia, and they are consistently recommended for individuals with type 2 diabetes to maintain normoglycemia (Chuwa *et al.*, 2021) ^[16]. Cereals provide essential carbohydrates (from sources like meat, wheat, and corn), proteins (from legumes and

pulses), fats (from peanuts, sesame, pumpkin, soybeans, pistachios, almonds, walnuts, and sunflower), and minerals (found in pearl millet, sorghum, millet, barley, and rye). While some foods are nutritious, others, particularly small grains and quinoa, offer digestible nutrients (Rodriguez *et al.*, 2020) ^[35]. This advantageous food group is characterized by a combination of nutrients with high bioavailability. In contrast to cereals, pseudocereals are defined as seeds or fruits that are not classified as grasses but are consumed similarly to cereals. Common pseudocereals include quinoa, chia, buckwheat, and amaranth seeds. Furthermore, pseudocereals may offer superior nutritional quality and health benefits compared to whole grains.

Seeds also serve as an excellent source of calcium, fibre, and phenolic compounds, which contribute to various health advantages. Research indicates that pseudo-cereal flour can effectively substitute wheat flour in a variety of food products, including those that are functional and gluten-free. Recently, pseudo-cereals have been successfully incorporated into the production of Special Purpose Foods (FOSHU), including bakery items, desserts, fermented drinks, and extruded goods. Consequently, the regular inclusion of pseudo-cereals in the diet holds significant promise for enhancing human nutrition and overall health. This study proposes innovative products that deliver high-quality offerings in medicine, food, and cognitive health, alongside health services. Figure 1 illustrates the health benefits associated with pseudo-cereals, particularly highlighting amaranth seeds.

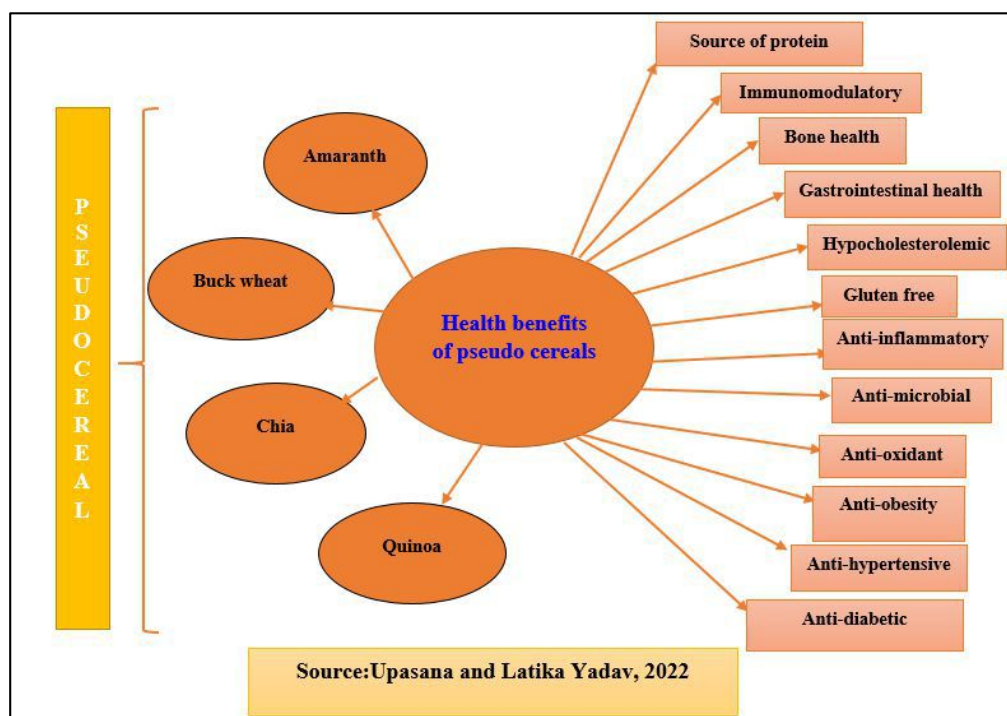


Fig 1: Illustrates the health benefits associated with pseudo-cereals, particularly highlighting amaranth seeds

Noncommunicable diseases (NCDs) are on the rise globally, primarily due to lifestyle choices such as smoking, insufficient physical activity, alcohol intake, and unhealthy diets characterized by high levels of salt, sugar, and fats, as well as the consumption of white bread, white rice, pasta, and other processed foods. These diseases are responsible for 41 million fatalities each year, representing 74% of all deaths worldwide. Annually, 17 million individuals succumb to NCDs before reaching the age of 70, with 86%

of these premature deaths occurring in low- and middle-income nations. Furthermore, 77% of all deaths attributed to NCDs take place in these regions. Heart disease stands as the foremost cause of death among noncommunicable diseases, accounting for 17.9 million fatalities annually, followed by cancer (9.3 million), chronic respiratory diseases (4.1 million), diabetes (including 2 million diabetics), and kidney disease, as reported by the World Health Organization in 2023.

The investigation into low glycemic index foods is crucial when combined with other strategies to address non-communicable diseases (NCDs) worldwide. This study has harnessed the nutritional advantages and health benefits of the underutilized pseudocereal, golden amaranth seed grain, in Tanzania. A comparative analysis is suggested between cereal grains and pseudocereals regarding their nutritional quality and health benefits, aiming to encourage the use of pseudocereals in developing nations.

Materials and Methods

Raw material

A one-kilogram bag of golden amaranth seeds was acquired from a local market in Morogoro and promptly delivered to the product laboratory within the Department of Food Science and Agro-processing at the Sokoine University of Agriculture, Morogoro, Tanzania. All chemicals and reagents utilized in this study are of analytical grade and sourced from Sigma Aldrich Inc., Germany. Additionally, Aluminum Laminated Pouches (ALP) were obtained from the same supplier. All treatments and analyses were conducted in triplicate, and the results are presented on a dry weight basis.

Preparation of raw material

Clean the seeds thoroughly to eliminate any contaminants and immerse them in still water at a 1:5 ratio overnight to detoxify. Following this, the seeds were washed, drained, and dried in a drying oven set at 60 ± 2 °C for three hours until achieving uniform moisture content. The dried seeds were then processed in a mixing machine (Havells, model MX-1155) and sifted through a 36 mm mesh sieve to produce fine and consistent flour (Chuwa *et al.* 2022)^[15]. To maintain freshness, store the flour in an airtight ALP bag to prevent moisture loss.

Quality evaluation of golden amaranth flour

Moisture content (%)

The moisture content of various samples was assessed using the AOAC (2012)^[5] method. Initially, weigh a new sample (5-10 g) and place it in the pan before weighing it with the iron. Subsequently, position the Petri dish in a hot air oven set at a temperature of 130-133 °C for 2 hours or until the weight remains constant. Once the drying process is complete, take out the Petri dish and allow it to cool in a desiccator filled with molten calcium chloride. Finally, weigh the pan containing the dried sample to ascertain the weight of the dry sample. The moisture percentage is then calculated as follows:

$$\text{Moisture (\%)} = \frac{\text{weight of fresh sample (g)} - \text{weight of dried sample (g)}}{\text{weight of fresh sample (g)}} \times 100$$

Dry matter content (%)

The dry matter constitutes the portion of a food sample that excludes water. It is calculated by assessing the percentage of moisture content and then subtracting this value from 100%.

$$\text{Dry matter (\%)} = 100\% - \text{Moisture content (\%)}$$

Protein (%)

The protein content was assessed following the methodology outlined in AOAC (2012)^[5] utilizing a semi-automatic device, specifically the KjeldTRON (KDIGB 6M

and KjeldISTEA). A moisture-free sample weighing 0.3 g was placed into digestion tubes that contained a catalyst mixture of potassium sulfate and copper sulfate in a ratio of 5:1. A total of six samples were processed simultaneously, including one blank that consisted solely of the catalyst mixture. To each tube, 10 mL of concentrated sulfuric acid was introduced, and the samples were digested at temperatures ranging from 360 to 400 °C within the digestion unit for a duration of up to 2 hours. Upon completion of the digestion, the tubes were allowed to cool until a clear bluish-green colour indicated that digestion was complete. Subsequently, the sample tubes were connected to the automatic distillation unit, where the aliquot was diluted and rendered alkaline by the addition of a 40 percent NaOH solution. The liberated ammonia was captured in a conical flask containing 25 mL of a 4 percent boric acid solution, along with 2-3 drops of methyl red and bromocresol green indicators. The resulting distillate was titrated with a standard 0.02 N H₂SO₄ solution until the endpoint, characterized by a pinkish-red colour, was reached, and the titre value was recorded. The total protein content was determined by multiplying the percentage of nitrogen by a factor of 6.25 for general protein calculations and by 5.71 specifically for soybean and soybean-derived products.

$$\text{Nitrogen (\%)} \times = \frac{\text{Titre value (mL)} \times \text{Normality of acid}}{\text{weight of sample (g)} \times 1000} \times 100$$

$$\text{Protein (\%)} = \text{Nitrogen \%} \times 6.25$$

Fat (%)

The AOAC (2010)^[4] method was employed for the determination of fat content utilizing the Automatic Soxhlet Apparatus (Soxtron). In preparation for analysis, solid samples were ground into a fine powder, while liquid samples were initially dried in a hot air oven at 60 °C before being converted into powder form. A sample weighing two grams (W) was measured and placed into the thimble, which was then positioned in the thimble holder. Subsequently, the thimble holder was aligned with a pre-weighed collection vessel (W₁) and secured within the apparatus. The fat extraction process was conducted at 80 °C for 45 minutes using 100 mL of petroleum ether (40-60 °C). Upon completion of the extraction, the excess solvent in the flask was recovered, and the residual fat in the collection vessel was dried at 80 °C in a hot air oven for one hour. After drying, the vessel was allowed to cool in a desiccator and was then weighed (W₂). The results were calculated as a percentage using the formula provided below:

$$\text{Fat (\%)} = \frac{W_2 - W_1}{W} \times 100$$

W=Weight of dried sample

W₁=Weight of empty Soxhlet flask

W₂= Weight of Soxhlet flask containing fat

Fibre (%)

The analysis of crude fibre was conducted utilizing the AOAC (2010)^[4] methodology within the FibroTRON Automatic Fiber Analysis System (Tulin Equipments). A one-gram sample (W) was accurately weighed and placed into a glass crucible, which was then positioned in the digestion block. Subsequently, 200 mL of 1.25 percent sulfuric acid was added, and the mixture was heated to 350

°C for 30 minutes. Following this, the crucible was allowed to cool, and the acid solution was carefully drained. The residue was then washed three times with hot distilled water. This procedure was repeated with 200 mL of 1.25 percent sodium hydroxide. After the second treatment, the crucible was transferred to a hot air oven for drying at a temperature range of 100-105 °C for 2 to 4 hours. Once dried, the material was cooled in a desiccator, weighed (W₁), and then subjected to ashing in a muffle furnace at 550-600 °C for 4-6 hours. After the ashing process, the crucible was again cooled in a desiccator and weighed (W₂). The crude fibre content was subsequently calculated and expressed as a percentage.

$$\text{Fibre} = \frac{W_1 - W_2}{W} \times 100$$

$$\text{Ascorbic acid (mg/100 g)} = \frac{\text{Titre value (mL)} \times \text{Dye factor} \times \text{Volume made up (mL)}}{\text{Aliquot of extract (mL)} \times \text{Weight of sample (g)}} \times 100$$

$$\text{*Dye factor} = \frac{0.5}{\text{Titre value of standard}}$$

β-carotene (mg/100 g)

A known mass of the sample, ranging from 2 to 5 grams when dried or 20 to 25 grams when fresh, was dissolved in acetone as the solvent. The sample was ground until the colour was fully extracted, resulting in a colourless residue. The resulting extract was then transferred to a separating

$$\beta\text{-carotene (mg/100 g)} = \frac{\text{Concentration (mg)} \times \text{Final volume (mL)} \times \text{Dilution (mL)}}{\text{Weight of sample (g)}} \times 100$$

Ash (%)

The total ash content was assessed gravimetrically (AOAC, 2012) [5] by utilizing a predetermined weight of samples contained in tared silica crucibles. Following the determination of moisture, the dried samples were gradually heated on a hot plate until the majority of the organic material was incinerated. Subsequently, the crucibles were transferred to a muffle furnace for ashing at a temperature of 550 °C, resulting in a carbon-free white ash of consistent weight. The ash content of the sample was then calculated and expressed as a percentage based on the fresh weight.

$$\text{Ash (\%)} = \frac{\text{Weight of ash (g)}}{\text{Weight of fresh sample}} \times 100$$

Total carbohydrates (%)

The total carbohydrate content was determined using the differential method outlined by AOAC (2010) [4].

$$\text{Total carbohydrates (\%)} = 100 - [\text{Protein (\%)} + \text{Fat (\%)} + \text{Ash (\%)} + \text{Moisture (\%)}]$$

Total energy (Kcal/100 g)

The total energy was determined through a differential method as outlined by AOAC (2010) [4].

$$\text{Total energy (Kcal)} = [(\text{Protein (g)} \times 4) + (\text{Fat (g)} \times 9) + (\text{carbohydrates (g)} \times 4)]$$

Minerals

Mineral analysis was conducted following the AOAC (1995) [6] methodology. The previously determined ash (as detailed in the crude ash determination) was allowed to cool. Subsequently, 15 mL of 6N HCl was introduced to the samples contained in crucibles, which were then transferred

Where:

W = Weight of dried sample

W₁ = Weight of crucible and content before ashing

W₂ = Weight of crucible containing ash

Ascorbic acid (mg/100 g)

The official method established by AOAC in 2004 [3] was utilized to determine the content of ascorbic acid. A three percent solution of meta-phosphoric acid was employed for the preparation of both the sample and the standard L-ascorbic acid. The sample underwent titration with 2, 6-dichlorophenol-indophenol dye until a light pink hue remained for a minimum of 15 seconds. The calculation of ascorbic acid content was performed according to the formula provided below.

funnel. Following the addition of petroleum ether and a 5 percent sodium sulfate solution, the coloured portion was collected. The final volume of the solution was adjusted to 25 mL. The optical density was measured at 452 nm, and the results were compared against a standard curve (Ranganna, 2009) [34]. The concentration of β-carotene in the sample was determined using the standard curve, with the quantity expressed in mg per 100 g

to 100 mL volumetric flasks. Distilled water was added to bring the total volume to the 100 mL mark. For the analysis of minerals, Atomic Absorption Spectroscopy (AAS) was employed, except for Potassium and Sodium, for which a Flame Emission Spectrophotometer (Model A-6200, Shimadzu, Corp., Kyoto, Japan) was utilized. Standards for Sodium and Potassium were prepared using their chloride salts, while the other minerals were obtained in their standard forms from the supplier.

Determination of amino acid profile of golden amaranth seeds

A pre-column derivatization of amino acids utilizing o-phthalaldehyde (OPA), followed by reversed-phase high-performance liquid chromatography (HPLC) with fluorometric detection, was conducted under the methodology outlined by Maria and Federico (2006), albeit with certain modifications. The samples underwent pretreatment, wherein 5 grams of both raw and processed amaranth were combined with 25 mL of hexane and allowed to stand for approximately 20 minutes. This mixture was then centrifuged at 3000 rpm for 10 minutes, filtered, and the supernatant was discarded. Protein extraction was performed following the procedure established with adaptations as noted. The defatted sample was subjected to protein extraction, which involved two extractions with 100 mL of water, the pH of which was adjusted to 9 using 1N NaOH while stirring for 20 minutes. Each extract was separated through centrifugation at 1000 rpm for 20 minutes. The extracts were combined, and the protein was precipitated by adjusting the pH to 4.5 with 1N HCl, followed by centrifugation. The resulting precipitate was redispersed in 100 mL of water, dissolved at pH 9, and re-

precipitated at pH 4.5. After centrifugation to separate the protein, it underwent two washes of 50 mL each at pH 4.5. The flour was then slurried and converted into a protein extract by adjusting the pH to 6.5-7 with 1N NaOH. The protein isolates were subsequently freeze-dried. Each trial was conducted in triplicate. Approximately 0.2 grams of protein isolate from each sample was measured into a clean, dry glass Pyrex test tube, to which 6N HCl containing 5 percent phenol was added. The tubes were placed in a dry ice-acetone bath, where the pressure inside the tube was reduced using a vacuum pump before sealing. Hydrolysis was carried out at 110 °C for 24 hours in an oven, after which the samples were cooled and centrifuged at 2000 rpm for five minutes to facilitate the descent of water droplets from the inner wall of the test tube to the solution level.

The test tubes were opened, and the resulting solution was transferred into an eggplant-shaped flask. The test tubes were then rinsed with fresh 6N HCl, and the washings were added to the flasks. Subsequently, the mixture was subjected to rotary evaporation at 50 °C. Any remaining HCl after the drying process was further dehydrated using NaOH pellets in a vacuum desiccator for 12 hours. For the sample diluent, 9.8 grams of sodium citrate were weighed and dissolved in 400 millilitres of distilled water within a 500 mL volumetric flask. To this solution, 8 millilitres of perchloric acid and 0.05 grams of caprylic acid were incorporated, and the volume was adjusted to the mark with distilled water. The pH of the resulting solution was modified to 2.2 using perchloric acid. The hydrolyzed sample was then dissolved in 2 millilitres of the prepared sample diluent. Regarding the standard amino acid solution, a mixed amino acid solution (H-type from Sigma Chemicals) was prepared by diluting 0.5 millilitres of the standard in 10 millilitres of the previously prepared sample diluent. The commercially available H-type mixed solution contains 17 amino acids and ammonia, each at a concentration of 2.5 µmol/mL. Consequently, the concentration in the diluted solution was 0.125 µmol/mL, which was subsequently combined with OPA solution at a 1:1 ratio for HPLC analysis.

The chromatography procedure adhered to the Agilent method as outlined by Mengerink *et al.* (2002). In summary, the hydrolyzed samples and amino acid standard solutions underwent automatic derivatization with an OPA solution in a 1:1 ratio. The OPA solution was prepared by combining 0.5 mg/ml of OPA with a borate diluent (pH 10.4), along with 0.1% (v/v) 2-mercaptoethanol and 0.1% (v/v) Brij 35. Following derivatization, 10 µl of each sample was injected into an ODS column (5 µm, 250 x 4.6 mm) at a temperature of 400 °C, with detection occurring at an excitation wavelength of 350 nm and an emission wavelength of 450 nm. Mobile phase A consisted of 40 mM KH₂PO₄, adjusted to pH 7.8 with NaOH, while mobile phase B was a mixture of acetonitrile, methanol, and water in a ratio of 45:45:10 (v/v/v). The separation process was conducted at a flow rate of 1 ml/min, utilizing a gradient program that maintained 0% B for 1.9 minutes, followed by a 16.3-minute increase to 53% B. A washing step at 100% B and subsequent equilibration at 0% B was carried out over a total duration of 30 minutes. The analysis was executed using an HPLC system (Model LC-10AS, Shimadzu Corp., Kyoto, Japan) equipped with a binary pump delivery system, a column thermostat, and a fluorescence detector. The detection of amino acids was based on the retention times established for

each amino acid under the specified experimental conditions.

Area = height x width (1/2 height)

NE~ norleucine equivalent = Area of norleucine peak/Area each Amino acid

S standard= NEstd*Molecular weight*µm Amino acid standard

$$\frac{C_g}{100} \text{ g protein} = \frac{NH \times (NH) \times S}{2} \text{ g/16 gN protein} =$$

D= dilution

SW= sample weight

V=volume loaded

NH=net height

C= concentration

S= constant for each amino acid in the standard mixture

Statistical analysis

The data was replicated and examined through Analysis of Variance (ANOVA) utilizing IBM SPSS (Statistical Package for the Social Sciences) version 27 (SPSS Inc., Chicago, USA).

Results and Discussion

Table 1: Nutritional Characteristics of Golden Amaranth Seed Powder

Parameters	Nutritional composition
Moisture content (%)	8.18±0.21
Dry matter content (%)	91.82±0.01
Crude protein (%)	18.98±0.13
Crude fat (%)	8.25±0.95
Crude fibre (%)	5.55±0.25
Total carbohydrates	65.27±0.45
Ascorbic acid (mg/100 g)	4.69±0.02
β-carotene (mg/100 g)	2.67±0.08
Ash (%)	3.05±0.12
Total energy (Kcal/100 g)	359.71±2.25

Crude protein

The crude protein content of raw grains, measured at 18.98%, falls within the previously reported range of 13.1% to 21% (Kariuki *et al.*, 2013) [21]. When compared to typical cereals, grain amaranth exhibits a comparatively high protein level, accompanied by a superior profile of essential amino acids. Additionally, the crude protein level observed in this study closely aligns with the findings of Abolaji *et al.* (2016) [1].

Crude fat

The crude fat content of the raw sample, measured at 8.25%, was found to be within the range of 5.60% to 10.9% as documented by Mlaka *et al.* (2009) [28] and Kariuki *et al.* (2013) [21]. However, it exhibited a significant difference ($p < 0.05$) when compared to the findings of Abolaji *et al.* (2016) [1].

Crude Ash

The crude ash content of raw grain amaranth, measured at 3.05%, falls within the range of 2.5% to 4.4% as documented by Mlaka *et al.* (2009) [28]. This finding is

noteworthy when compared to the ash content reported by Abolaji *et al.* (2016)^[1] in their study of grain amaranth.

Crude fiber

The crude fibre content of raw grain amaranth, measured at 5.55%, exceeds the range of 3.1% to 5% reported by Kariuki *et al.* in 2013^[21].

Total Carbohydrates

The grain amaranth contains a significant carbohydrate content of 65.27%, which falls within the range of 55% to 69% reported by Kariuki *et al.* in 2013^[21]. This level is lower compared to that of cereals, root tubers, and bananas. Consequently, amaranth seeds can be utilized to create low glycemic index foods suitable for individuals with type one and type two diabetes. According to the findings of Stephen *et al.* (2013)^[41], the composition of carbohydrates, fats, and proteins in amaranth enables a more balanced nutrient intake with smaller quantities compared to other cereals. Therefore, the nutritional profile of amaranth, including its protein, carbohydrate, fat, ascorbic acid, β -carotene, and energy content, indicates that this grain is rich in essential nutrients that can promote healthy living and contribute to food security.

Dry matter content

The current study indicates that the dry matter content of grain amaranth seeds is 91.82%. This finding suggests that amaranth seeds are abundant in nutrients, which can significantly contribute to addressing nutritional deficiency diseases and non-communicable diseases.

Ascorbic acid

The ascorbic acid content in golden amaranth seeds is measured at 4.69 mg per 100 grams. Ascorbic acid serves multiple roles, including acting as a cofactor, complementing enzymes, functioning as a co-substrate, and serving as a potent antioxidant in numerous biochemical reactions and metabolic pathways. Additionally, it plays a crucial role in stabilizing vitamin E and folic acid while improving iron absorption. Furthermore, it effectively neutralizes free radicals and toxins and mitigates inflammatory responses, such as those seen in sepsis syndrome.

β -carotene

The current study indicates that the content of β -carotene, also known as provitamin A, is measured at 2.67 mg per 100 grams. Vitamin A is a fat-soluble vitamin found naturally in a variety of foods. It plays a crucial role in maintaining normal vision, supporting the immune system, facilitating reproduction, and promoting growth and development. Additionally, vitamin A is essential for the proper functioning of the heart, lungs, and other vital organs. Carotenoids, which are pigments responsible for the yellow, orange, and red hues in fruits and vegetables, can be converted by the body into vitamin A. A deficiency in β -carotene or provitamin A can result in serious consequences, such as xerophthalmia, a condition characterized by difficulty seeing in low light, which may lead to blindness if left untreated. Prolonged vitamin A deficiency can also elevate the risk of respiratory illnesses, including pneumonia, as well as infections such as measles and diarrhoea. Furthermore, it may lead to anaemia, a condition

where red blood cells fail to deliver sufficient oxygen to the body. In extreme cases, inadequate vitamin A intake can significantly increase the risk of mortality.

Total Energy

The powder derived from golden amaranth seeds has an energy content of 359.71 Kcal per 100 grams. This figure is considerably greater than the value reported by Abolaji *et al.* (2016)^[1]. In their analysis, Chemed and Bussa (2018) examined raw amaranth and found no significant differences in energy content. The energy level identified for amaranth grain exceeds the 251 kcal per 100 grams noted by Emire and Arega (2012)^[18], yet it is lower than the 371 kcal per 100 grams documented by Caselato-Sousa and Amaya-Farfán (2012)^[10] in their studies on amaranth grains. The calorie values observed are also higher than those for tef grains, which contain 336 kcal per 100 grams (Bultosa, 2016)^[9], due to amaranth grains having elevated levels of proteins and fats compared to tef grains.

Table 2: Mineral content of golden amaranth flour

Parameters (mg/100 g)	Mineral composition
Iron	69.24±0.002
Zinc	12.31±0.001
Calcium	182.21±0.07
Magnesium	292.15±0.001
Manganese	6.032±0.24
Potassium	407.13±0.006

Table 2 presents the values of iron (69.24 mg/100 g), zinc (12.31 mg/100 g), calcium (182.21 mg/100 g), magnesium (292.15 mg/100 g), manganese (6.03 mg/100 g), and potassium (407.13 mg/100 g) obtained in this study. These values are comparable to or exceed those reported by Stephen *et al.* (2013)^[41] for zinc and manganese. Notably, the current study indicates higher levels of zinc and potassium than those found in the research conducted by Singh and Punia (2020)^[37]. Furthermore, the findings reveal that amaranth grain is a significant source of iron, with a content of 66.0 mg/100 g, in contrast to the 16.8-21.0 mg/100 g reported by Stephen *et al.* (2013)^[41] and the 13.0 mg/100 g for iron and 4.8 mg/100 g for zinc noted by Mburu *et al.* (2012)^[25]. It is important to highlight that iron is essential for various enzymes involved in oxygen metabolism, and its deficiency can lead to anaemia, which diminishes oxygen-carrying capacity and disrupts aerobic functions. As concluded by Stephen *et al.* (2013)^[41], the balanced composition of carbohydrates, fats, and proteins in amaranth facilitates a more efficient nutrient uptake with lower consumption levels compared to other cereals. This characteristic may contribute to addressing the macro- and micronutrient deficiencies prevalent in Sub-Saharan Africa. Additionally, noted that the consumption of grain amaranth offers nutritional and health benefits, including significant improvements in the well-being of severely malnourished children and enhancements in body mass index for individuals affected by HIV/AIDS. Consequently, the proximate analysis of protein, carbohydrate, fat, ash, and energy indicates that the grain amaranth examined in this study is rich in balanced nutrients that can promote healthy living and food security.

Table 3: Amino acid profile of golden amaranth powder

Parameter	Amino acid (g/Ng)
Lysine	7.89±0.17
Histidine	2.03±0.007
Threonine	4.98±0.15
Methionine	2.83±0.32
Isoleucine	3.76±0.09
Leucine	6.39±0.03
Phenylalanine	3.79±0.14
Aspartic acid	10.87±0.16
Glutamic acid	17.34±0.06
Alanine	6.83±0.04
Arginine	14.97±0.21
Cystein	3.96±0.56
Valine	4.82±0.45
Serine	8.63±0.05
Tryptophan	1.59±0.09
Glycine	14.68±0.05
Tyrosine	0.62±0.06

Table 3 demonstrates that golden amaranth seeds represent the most abundant source of amino acids, including Glutamic acid, Glycine, Arginine, Aspartic acid, Serine, Lysine, Alanine, Leucine, Threonine, and Valine. The findings of this research align with those reported by Njoki in 2015. Amino acids are essential for the synthesis of body proteins and other significant nitrogen-containing compounds, such as creatine, peptide hormones, and certain neurotransmitters. While dietary allowances are typically expressed in terms of protein, the actual biological requirement pertains to amino acids. The body continuously degrades and resynthesizes proteins and other nitrogenous compounds. The turnover of protein within the body daily far exceeds the amount typically consumed, highlighting the importance of amino acid reutilization in protein metabolism. There are nine amino acids histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine that mammals cannot synthesize, making them essential dietary nutrients. These are referred to as essential amino acids. Although histidine is recognized as essential for infants, its necessity for adults has only recently been established. While arginine can be synthesized by mammals, it is often insufficient to meet the needs of young individuals in most species. Amino acids consumed in excess of what is required for the synthesis of nitrogenous tissue are not stored; instead, they are degraded, with nitrogen being excreted as urea. The remaining keto acids, after the removal of amino groups, can either be used directly for energy or converted into carbohydrates or fats.

Health benefits of Amaranth

Rich source of protein

Amaranth grains are recognized for their elevated protein content, measuring 18.98±0.13 percent, with particularly high levels of lysine (7.89±0.17 g/N) and tryptophan (1.59±0.09 g/N). These amino acids are often limited in traditional cereals such as wheat, rice, and maize, although amaranth is noted to be deficient in leucine. Previous research has indicated that amaranth is also relatively abundant in sulfur-containing amino acids, which are typically scarce in legumes (Maurya and Arya 2018) [23]. It is widely acknowledged that protein is essential for the growth and maintenance of all body cells, supports neurological functions, aids in digestion, naturally regulates

hormone levels, and helps sustain the immune system (Soriano-Garcia and Aguirre-Diaz 2019) [38-40].

Reduces inflammation

Inflammation is widely recognized as a natural immune response aimed at safeguarding the body from infections and injuries. However, persistent inflammation may be linked to conditions such as diabetes, cancer, and various autoimmune disorders (Soriano-Garcia and Aguirre-Diaz 2019) [38-40]. Previous research has indicated that the intake of amaranth can mitigate inflammation associated with these diseases. This effect is attributed to the ability of extruded amaranth protein hydrolysates to activate bioactive peptides, which in turn diminish the expression of numerous pro-inflammatory markers.

Health of the bone

Golden amaranth seeds have been identified as a significant source of calcium, with a concentration of 182.21±0.07 mg per 100 grams, as indicated by the current research. This level of calcium is eighteen times greater than that found in pumpkin seeds, according to the findings of Elinge *et al.* (2012) [17]. Furthermore, golden amaranth seeds contain nearly three times the calcium found in groundnut seeds and more than double the calcium present in sunflower seeds, as reported by Muttagi and Joshi (2020) [29]. Calcium plays a crucial role in maintaining healthy bones within the human body. The data suggests that amaranth seeds possess a higher calcium content than other seeds, making them beneficial in the prevention of osteoporosis and various other bone-related health issues. Consequently, previous studies have indicated that consuming extruded amaranth products can assist individuals in meeting their calcium requirements for optimal bone density (Soriano-Garcia and Aguirre-Diaz 2019) [38-40].

Cholesterol-lowering effect

Previous research has indicated that amaranth oil contributes to a reduction in total and LDL (low-density lipoprotein) cholesterol levels while simultaneously promoting an increase in HDL (high-density lipoprotein) cholesterol in an experimental animal model (Soriano-Garcia and Aguirre-Diaz 2019; Berger *et al.*, 2003) [38-40, 7, 8]. Furthermore, findings suggest that amaranth influences cholesterol absorption, bile acid production, hepatic cholesterol levels, cholesterol lipoprotein distribution, and cholesterol biosynthesis (Soriano-Garcia and Aguirre-Diaz 2019; Mendonça *et al.*, 2009) [38-40, 26].

Fights against duodenal peptic ulcers

Previous research has indicated that Amaranth oil has the potential to treat duodenal peptic ulcers and chronic gastritis associated with *Helicobacter pylori* (Soriano-Garcia *et al.*, 2018; Cherkas *et al.*, 2018) [38-40].

Fights against diabetes

The inclusion of amaranth in the diet assists diabetic patients in managing their blood glucose levels, primarily due to its elevated manganese content, which plays a crucial role in the gluconeogenesis pathway. Additionally, manganese contributes to the maintenance of the immune system, regulation of cholesterol levels, and supports skin and bone health, as well as renal function.

Gluten-free

Amaranth is regarded as a highly beneficial source of gluten-free protein, making it suitable for individuals with coeliac disease and those seeking to adopt a gluten-free diet in their daily lives.

Helps pregnant women

Folic acid is recommended for pregnant women to include in their diet to help prevent birth defects such as spina bifida and congenital heart conditions. Amaranth is noted for its folic acid content, which is 88.0 mcg, making it advantageous for the formation of new cells. Consequently, this can assist pregnant women in reducing the likelihood of developmental defects in the fetus.

Prevents constipation

Amaranth is widely recognized as an excellent source of soluble dietary fibres. These dietary fibres are known to facilitate bowel movements, thereby assisting individuals in the prevention of constipation.

Antioxidant property

Antioxidants are often referred to as "free radical scavengers." These substances play a crucial role in preventing oxidation, thereby reducing the likelihood of infections, supporting cardiovascular health, and mitigating the risk of various cancers and degenerative diseases. In amaranth, the antioxidant properties are primarily due to the presence of phenolic compounds and flavonoids. Research indicates that the flowers and leaves of *Amaranthus*, along with their extracts, exhibit the highest levels of antioxidant activity compared to other parts, with rutin identified as the principal radical scavenger (Soriano-Garcia and Aguirre-Diaz 2019; Peter and Gandhi, 2017) ^[38-40].

Amaranth is a superfood that provides optimum nutrition for maintaining good health

Numerous studies have previously indicated that amaranth contributes to various physiological functions within the human body. It serves multiple roles, including antimicrobial, hepato-protective, anti-cancer, anti-malarial, anti-anemic, and as a supplementary or nutraceutical food. Its classification as a superfood is attributed to its rich content of iron, manganese, calcium, dietary fibres, essential amino acids, lipids, and antioxidants, all of which are essential for maintaining a healthy lifestyle.

Conclusion

Grain amaranth has been identified as a rich source of nutrients, particularly in terms of protein and essential minerals. Notably, the minerals that stand out include calcium, iron, and zinc. The amino acid profile of grain amaranth (*A. albus*) is particularly advantageous for human nutritional needs, with high levels of lysine and sulfur-containing amino acids such as methionine, cysteine, and cystine. The significant presence of essential amino acids suggests that amaranth grain can serve as a valuable addition to low-protein diets. Consequently, this pseudo-cereal has the potential to enhance staple foods, thereby addressing malnutrition among vulnerable populations. Additionally, its total carbohydrate content of 65.27% is relatively low, making it a suitable option for individuals with type 2 diabetes and those who are obese, as it contributes to a low glycemic index diet.

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