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Physiochemical and Technological Properties of Some Colored Quinoa Varieties

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ABSTRACT

Quinoa (*Chenopodium quinoa Willd*) is a promising seed due to its exceptional nutritional profile. This study evaluated different colored quinoa seed varieties; white, red, black, and their mixtures with a focus on their potential as functional foods and the benefits of calcium fortification. The investigation included assessments of physical, chemical, color, and phytochemical properties of the raw seeds, as well as changes in saponin content after soaking and poaching. Poached and calcium-fortified quinoa samples were then examined for their nutritional composition, sensory attributes, and storage stability after 15 day in the refrigerator at 5°C. Results showed that white quinoa had the highest lightness (L*) and yellowness (b*), total carbohydrate content and sensory acceptance after poached and calcium fortification.while red quinoa was higher hectoliter weight, redness value, and anthocyanin contents, as well as it was richer in protein and fat (15.17 and 7.56%, respectively) and black quinoa contained more fiber (6.08%), antioxidants (47.90%), Ca and Fe. The saponin levels significantly decreased after the soaking and poaching process. Calcium fortification enhanced mineral content without negatively affecting sensory quality. All samples remained microbiologically safe and within acceptable pH limits during refrigerated storage. The findings support the use of colored quinoa, particularly in combination, for the development of calcium-fortified functional food products with improved nutritional and health benefits. It could be recommended to produce poached colord quinoa products for age (3-10 years), where it provides children with a part of their daily requirements of protein, energy, calcium, iron and zinc.

1. Introduction

Quinoa (*Chenopodium quinoa* Willd.) is a pseudo-cereal belonging to the family *Chenopodiaceae*. It can thrive under diverse environmental conditions due to its tolerance to salinity, drought, and cold, and requires minimal water and fertilizer inputs (Pathan and Siddiqui, 2022). World quinoa production amounted to approximately 112,251 tons (FAOSTAT, 2023). Among its main varieties white, red, and black differences in nutritional quality have been observed, with red and black quinoa showing higher antioxidant capacity than white quinoa and other cereals (Chen et al., 2023). Quinoa seeds are nutritionally rich, containing carbohydrates, proteins, fats, fibers, and essential minerals such as calcium, potassium, and zinc (Sobotta et al., 2020). They also provide phenolic compounds, phytosterols, vitamins, and amino acids, making quinoa a valuable alternative grain, particularly in regions where traditional crops are limited (Hussain et al., 2021; Mu et al., 2023). Despite its nutritional advantages, quinoa seeds often have a naturally bitter taste caused by water-soluble saponins concentrated in the seed coat. These compounds are usually reduced through washing or grinding to improve palatability (Thakur et al., 2021; Almaguer et al., 2023). Beyond their impact on taste, saponins play protective roles for the plant and it potential health benefits, including

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anticancer, anti-obesity, an-tioxidant, and cardioprotective effects (Khadija et al., 2020). Saponin content varies widely among genotypes, ranging from less than 0.1% in "sweet" types to more than 1% in "bitter" varieties, with some exceeding safe limits for consumption which is 120mg/100g (Mora-Ocasion et al., 2022). Quinoa has shifted from being a traditional Andean staple to a globally recognized commercial crop. It is now widely traded internationally and incorporated into a variety of food products, ranging from plain grains to ready-to-cook meals (Melini et al., 2023). Its versatility allows for use in salads, soups, and baby food, as well as incorporation into functional food formulations to enhance nutritional value (Sezgin and Sanlier, 2019). The demand for plant-based milk substitutes has increased worldwide due to the numerous positive health effects of phenolic compounds and suitability for individuals with lactose intolerance or milk allergies (Aydar et al., 2020). Cereal-based non-dairy milk are considered functional foods, and quinoa stands out as a promising raw material due to its high protein content, essential amino acids, low glycemic index, and gluten-free nature (Angeli et al., 2020; Kohajdová et al., 2023). Quinoa-based milk may therefore serve as an alternative for celiac patients and as an affordable substitute in developing countries and regions with limited access to dairy products (Galindo-Luján et al., 2021; Salwa, 2019). Heat treatment remains one of the most essential technologies in food preservation, particularly through pasteurization and sterilization, and is among the most widely applied methods in the food industry. It ensures the production of safe foods that consumers can rely on while preserving nutrient quality and enhancing the value of agricultural products. Moreover, it provides safe, ready-to-consume nutritional properties comparable to those of fresh foods, extends shelf life, and thereby increases the overall added value of the products (Marger et al., 2018, Anwar et al., 2020 and Rajput et al., 2022). Calcium deficiency remains a global nutritional concern, contributing to rickets, osteomalacia, and other health complications. Fortification of foods with calcium is widely recognized as an effective strategy to improve intake, especially in populations with limited dairy consumption. Incorporating calcium into plant-based foods may provide an accessible and sustainable approach to addressing this deficiency (Cormick et al., 2021; Palacios et al., 2021). In light of these considerations, the present study aimed to assess the physicochemical properties of colored quinoa seeds (white, red, black, and their blends) and to develop an innovative gluten-free and lactose-free product consisting of preserved poached colored quinoa seeds combined with quinoa-based milk. This research specifically addressed the gap in developing nutrient-dense, non-dairy, shelf-stable products that integrate the health benefits of quinoa with the advantages of fortification and preservation techniques of food. In addition, the study evaluated the physicochemical composition, nutritional profile, sensory attributes, and storage stability of the developed products.

2. Materials and Methods

Materials

White (LP 128), red (PL 2034) and black (Colorado 407 D) quinoa varieties were obtained from Central Laboratory for Agricultural Climate, A. R. C., Giza, Egypt. (Figure1). A mixed sample was prepared by combining equal proportions of the three varieties. Food-grade vanilla and sugar were purchased from the local market. Calcium acetate, ascorbic acid, citric acid, DPPH (2,2-diphenyl-1-picrylhydrazyl), gallic acid, catechin, catechol chemicals were obtained from Sigma-Aldrich Chemical Company, Saint Louis (USA). The Folin reagent was purchased from LOBA-Chemie (India), and the other standard suppliers.

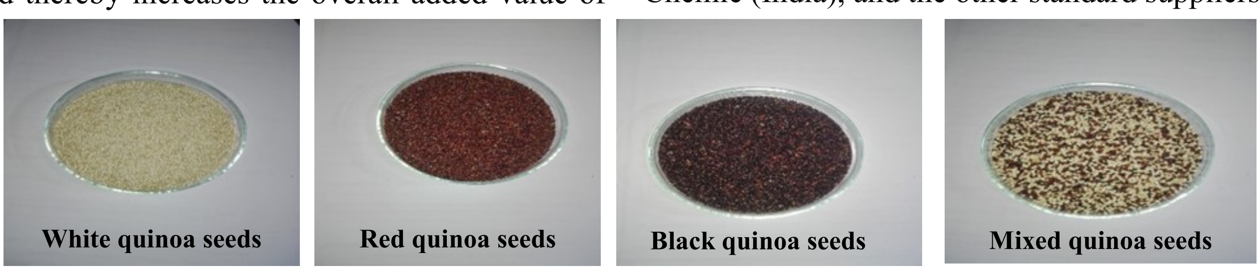

Figure 1. Photos of the tested quinoa seeds varieties

Methods

Physical properties of raw colored quinoa seeds

Quinoa seeds were manually cleaned to remove dust and other extraneous materials then stored at room temperature in glass containers until use. Subsequently, the seeds were analyzed to determine their physical properties as follows:

The bulk density

Bulk density, defined as the ratio of seed weight to its total volume, was determined using a 250ml cylinder. The volume and weight were then recorded (Wongsa et al., 2016)

$$\text{Bulk density} = \frac{\text{weight of Quinoa seeds (g)}}{\text{volume of Quinoa seeds } (cm^3)}$$

Weight of 1000-seed

The weight of 1000-seed was measured using cleaned seed samples. The seeds were counted by an Automatic seed counter and weighed in triplicate; the average weight was extrapolated to 1000 seeds ISTA (1996)

Hectoliter Weight

Hectoliter weight was determined according to the standard methods of AACC (2000) and expressed in kilograms per hectoliter (Kg/h1).

Color attributes

The color of raw colored quinoa seeds and poached quinoa seed samples was measured using a hand-held chromameter (CR-400, Konica Minolta, Japan) according to the method described by McGuire (1992). Results were expressed as L* (lightness), a* (redness–greenness), and b* (yellowness–blueness).

Proximate chemical composition

Moisture, crude protein, fat, crude fiber and ash content of raw colored quinoa seeds and poached colored quinoa (control and fortified) samples were determined according to AOAC (2019). Total carbohydrates content was calculated by difference.

Phytochemical characteristics of colored quinoa seeds

Total phenolic content

The Total phenolic content (TPC) of raw colored quinoa seeds was determined using Folin–Ciocalteau method as described by Kaluza et al. (1980). Results were expressed as milligrams of gallic acid equivalents (mg GAE/100g) on a dry weight basis.

DPPH radical scavenging activity

The free radical scavenging activity of raw colored quinoa seeds was determined using the 2.2-diphenyl-2-picryl-hydrazyl (DPPH) method according to Fischer et al. (2013). Antioxidant activity was calculated using the following equation:

DPPH radical-scavenging activity (%) = $[(A_0 - B_1)/A_0] \times 100$

Where: A_0 and B_1 are the absorbance of control and sample after 30 min, respectively.

Carotenoids content

The carotenoids content of raw colored quinoa seeds determined according to AOAC (2019) and calculated as follows:

$$\text{Carotenoids } (\mu g/g) = \text{Absorbance} \times 30.1$$

Total anthocyanin content

The total anthocyanin content of raw colored quinoa seeds was determined according to Giusti and Wrolstad (2001), and calculated as follow:

Monomeric Anthocyanin Pigment (mg L^{-1}) = (Ax MW× DF×1000) / (ε x 1)

Where, A: is absorbance calculated as:

$A=[(Abs_{510} - Abs_{700})_{pH\ 1.0} - (Abs_{510} - Abs_{700})_{pH\ 4.5}]$

MW: is the molecular weight for cyanidin-3-glucoside = (449.2g mol^{-1}), DF: is the dilution factor, ε: is the molar absorbance of cyanidin-3-glucoside= (26,900L/(cm×mol)), L: is cell path length (1cm), and 1000 is the conversion factor from mL to L.

Functional properties of poached colored quinoa seeds

Water uptake ratio

Water uptake was determined according to Sareepuang et al. (2008)

$$\text{water uptake ratio} = \frac{\text{weight of poached quinoa seeds } (g)}{\text{weight of soaked quinoa seeds } (g)}$$

Volume increase ratio

Volume increase was determined according to Prasert and Suwannaporn (2009) The volume increase ratio was calculated as follows:

$$\text{Volume increase ratio} = \frac{\text{volume of poached quinoa seeds (ml)}}{\text{volume of sosked quinoa seeds (ml)}}$$

Total saponin

Total saponin content of colored quinoa seeds before and after poaching. For saponin extraction, one gram of each flour sample was mixed with 30mL of ethanol and kept at ambient temperature for 30 minutes. The suspension was then filtered, and 0.25 mL of the clear extract was evaporated to dryness in a water bath at 65°C for about 5 minutes. Subsequently, 0.5mL of vanillin in ethanol (4%) and 2.5mL of H_2SO_4 (72%) were added to each tube, vortexed, incubated in a water bath at 60°C for 15 minutes, and cooled to room temperature. Absorbance was measured at 560 nm using a spectrophotometer (Biosystem 310) (Le et al., 2018). A standard curve was prepared by plotting absorbance against concentration, and total saponin content was expressed as mg aescin equivalents per gram dry weight of flour (mg/100g).

Preparation of Quinoa-based milk

Quinoa-based milk procedure is shown in Figure 2 as described by Livia et al. (2015) with some modification of total solid content of quinoa-based milk was determined according to the method followed by Kim et al. (2012).

Cleaned Quinoa seeds

⬇

Soaking Quinoa seeds in tap water (1**:5**) 25ºC for 6 hrs.

⬇

Draining the soaking water and rinsing the seeds twice with tap water

⬇

Boiling for 15 min in tap water 1**:**5

⬇

Draining the boiling water

⬇

Blending the boiled seeds with water (1**:3 w/v**) at 25°C for 7 min

⬇

Filtration

⬇

Quinoa milk

⬇

Modification of total solid of Quinoa milk

⬇

Quinoa milk resultant

⬇

Adding calcium citrate 0.97g /100g (not added to the control samples)

⬇

Pasteurization at 72˚C/2min.

⬇

Quinoa based milk

Figure 2. Flow chart of the preparation of Quinoa-based milk

Sensory evaluation

Sensory evaluation was carried out by ten trained panelists from the Crop Technology Research Department, Food Technology Research Institute, Agricultural Research Center, Giza, Egypt. A 9-point hedonic scale (1 = strongly dislike to 9 = strongly like) was used to assess color, taste, odor, texture, and overall acceptability (Meilgaard et al., 1991).

Minerals content

Calcium, iron, and zinc contents of calcium-fortified poached colored quinoa (control and fortified) samples were determined using a flame photometer (Galienkamp FGA 330, England) and a Perkin Elmer Atomic Absorption Spectrophotometer (Model 80, England), following the AOAC (2019) method.

Energy value

The energy value of poached colored quinoa (control and fortified) samples was calculated using the following equation as by James (1995):

$$Energy\ value\ \left(\frac{Kcal}{100g}\right) = 4\,(g\ protein + g\ carbohydrates) + 9\,(g\ fat)$$

Nutritional value for the products

The nutritional values of both the control and fortified qunioa samples were computed using (DRI, 2001 and DRI 2002/2005) guidelines to assess the extent of nutrient enrichment.

pH Measurements

pH values of control and calcium-Fortified poached preserved colored quinoa samples were measured at 20°C using a digital pH meter following of AOAC (2019) method.

Microbiological analysis

The microbiological aspets of control and calcium-Fortified poached preserved colored quinoa samples was evaluated according to APHA (2001). Total bacterial count, as well as yeast and mold counts were determined at the time of manufacture (zero time) and after 15 day of storage in refrigerator at 5°C. Results were expressed as colony-forming units per gram (CFU/g).

Statistical analysis

The collected data were analyzed using analysis of variance (ANOVA) according to Steel et al. (1996). Means were compared using Duncan's multiple range test at the 5% significance level.

Preparation of control and calcium-fortified poached quinoa samples

Quinoa seeds were cleaned and washed with water at 60°C under agitation for 20 minutes using a seed-to-water ratio of 1:10 (w/w). The washing water was drained, and the seeds were rinsed twice with clean water. The seeds were soaked for 8 hours, after which the soaking water was discarded and the seeds were rinsed again twice. Then, the washed seeds were steamed at 100°C for 10 minutes to obtain poached quinoa seeds. .Each sample of poached colored quinoa was mixed with its corresponding quinoa milk fortified with calcium at a ratio of 1:1 to prepare eight formulations (W Con, W Forti, R Con, R Forti, B Con, B Forti, M Con, and M Forti).

The preservation process of control and calcium-fortified poached quinoa samples

Each sample of poached colored quinoa was mixed with the quinoa -based milk derived from it (1:1 ratio) then packed in clean sterilized jars

↓

Adding, ascorbic acid 0.01g and citric acid 0.1g

↓

Pasteurization (72°C / 2min.)

↓

Preserved quinoa products (Final Product)

↓

Storage (5°C / 15 day) in refrigerator

Figure 3. Flow chart of the preservation process of poached quinoa seeds

Preserved white quinoa seeds (w Con and w Forti) | Preserved red quinoa seeds (R Con and R Forti) | Preserved black quinoa (B Con and B Forti) seeds | Preserved mixed quinoa seeds (M Con and M Forti)

W Con, R Con, B Con and M Con = Control of milk-poached colored quinoa samples (without calcium) for, white quinoa, red quinoa black quinoa and mixed quinoa respectively; w Forti, R Forti, B Forti, and M Forti = calcium- Fortified milk poached quinoa samples for white quinoa, red quinoa, black quinoa and mixed quinoa respectively

Figure 4. Final products: preserved poached colored quinoa samples

3. Results and Discussion

Physical properties of raw colored quinoa seed varieties

Physical properties, including bulk density, 1000-seed weight, and hectoliter weight of raw colored quinoa seed varieties, are presented in Table 1. The bulk density ranged from 0.760 to 0.767g/cm³, and no differences were observed between them. 1000-seed weight is a seed quality determinant, ranging from 2.90 to 3.70g. Red and black quinoa seeds recorded the highest 1000-seed weights (3.70g and 3.50g, respectively), followed by white quinoa seeds (3.20g). The hectoliter weight significantly increased in red quinoa seeds, followed by black quinoa seeds (83.76 and 83.06kg/hl); on the contrary, mixed quinoa seeds had the lowest 1000 seed weights (2.90g) and hectoliter weight (80.37kg/hL). These values were close to the results of (Ray et al. 2021 and De Bock et al. 2021).

Color attributes of raw colored quinoa seed varieties

The color attribute values of raw colored quinoa seed varieties are summarized in Table 2. The color attributes varied significantly among the quinoa varieties of values L*, a*, and b*. White quinoa exhibited the highest lightness (L*) and yellowness (b*), with values of (82.55 and 19.15), respectively, while showing the lowest redness (a*) value, 1.90. Red quinoa recorded the greatest redness (a*) 7.09 due to the presence of high anthocyanin content. In contrast, black quinoa showed the lowest values (49.19 and 1.55) respectively for lightness and yellowness. These differences reflect the influence of seed coat pigmentation which are in agreement with the ranges reported by De Bock et al. (2021). The increased red color of red quinoa is due to betacyanins rather than anthocyanin, as reported by Tang et al. (2015).

Table 1. Physical properties of raw colored quinoa seeds varieties

Samples	Bulk density (g/cm^3)	Weight of 1000-seed (g)	Hectoliter (kg/hL)
White quinoa seeds	0.760±0.001^a	3.20±0.11^b	81.24±0.12^c
Red quinoa seeds	0.767±0.02^a	3.70± 0.11^a	83.76±0.13^a
Black quinoa seeds	0.761±0.01^a	3.50±0.10^a	83.06±0.09^b
Mixed quinoa seeds	0.763±0.002^a	2.90± 0.12^c	80.37±0.11^d

Means with different letters in a column are significantly different at the 0.05 level of significance.

Table 2. Color attributes of raw colored quinoa seed varieties

Samples	*L**	*a**	*b**
White quinoa seeds	82.55±0.32^a	1.90±0.02^d	19.15±0.09^a
Red quinoa seeds	50.94±0.42^c	7.09±0.14^a	5.49 ± 0.10^c
Black quinoa seeds	49.19±0.22^d	3.65±0.33^c	1.55±0.29^d
Mixed quinoa seeds	62.49±0.26^b	4.27±0.08^b	11.05±0.11^b

Means with different letters in a column are significantly different at the 0.05 level of significance

Chemical composition of raw colored quinoa seed varieties

Table 3 presents the chemical composition of raw colored quinoa seeds. The chemical composition of the quinoa varieties showed notable differences among the varieties. The results indicate that White quinoa seeds had the highest carbohydrate content (73.27%) but the lowest fat and fiber (5.56% and 5.18% respectively). Red quinoa was distinguished by its higher protein and fat levels (15.17%) and (7.56%), whereas black quinoa seeds contained the highest crude fiber and ash contents (6.08% and 2.74%). The mixed quinoa seeds showed intermediate values between the single colored seeds. These variations may be attributed to genetic and environmental factors, such as soil conditions, fertilizer type, genetic differences, and the timing of harvest (Pathan and Siddiqui 2022), and the results are consistent with those reported by Yang et al. (2024) and Zahra Farajzadeh et al. (2020).

Table 3. Chemical composition of raw colored quinoa seed varieties

Samples	Protein %	Fat%	Fiber %	Ash%	Carbohydrate %
White quinoa seeds	13.73 ^{b} ± 0.07	5.56^{c}±0.23	5.18^{c}±0.09	2.26^{b}±0.08	73.27^{a} ± 0.21
Red quinoa seeds	15.17 ^{a} ± 0.05	7.56^{a}±0.25	5.60^{b}± 0.12	2.19^{b}±0.09	69.48^{d}± 0.09
Black quinoa seeds	12.65 ^{d} ± 0.12	6.40^{b}±0.32	6.08^{a}± 0.03	2.74^{a}±0.10	72.13 ^{c} ± 0.11
Mixed quinoa seeds	13.29 ^{c} ± 0.03	6.32^{b}±0.12	5.56^{b}±0.11	2.29^{b}±0.03	72.54 ^{b} ± 0.21

Means with different letters in a column are significantly different at the 0.05 level of significance.

Phytochemicals of raw colored quinoa seed varieties

The colored quinoa seeds (white, red, black, and mixed) have statistically significant differences in the contents of total phenols, carotenoids, antioxidants, and anthocyanins, as shown in Table 4. The phytochemical analysis revealed significant varietal differences. White quinoa had the lowest contents of phenolics, antioxidants, carotenoids, and anthocyanins. Red quinoa was characterized by the highest anthocyanin content (718.23mg/100g) followed by mixed quinoa seeds (317.43mg/100mg/100g), while black quinoa showed the greatest antioxidant activity (47.90 %) compared to the other quinoa seeds. Both red and black quinoa recorded elevated carotenoid levels (5.34 and 5.15µg/g respectively) compared to the mixed and white varieties (3.64 and 2.67µg/g respectively). A positive correlation was observed between antioxidant activity and total phenolic content. These findings are in line with previous reports by Yang et al. (2024), Zhang et al. (2024), Ballester-Sánchez et al. (2019), and Chen et al. (2023).

Table 4. Phytochemicals of raw colored quinoa seed varieties

Samples	T .phenol (mg AE/100g)	Antioxidant %	Carotenoid (µg/g)	Anthocyanin mg/100g
White quinoa seeds	140.15^{b}± 0.25	25.04^{d} ± 0.11	2.67^{c}± 0.27	66.65 ± 0.35^{d}
Red quinoa seeds	173.91^{a}± 0.28	41.21^{b} ± 0.25	5.34^{a}±0.10	718.23±0.15 ^{a}
Black quinoa seeds	174.17^{a}± 0.30	47.90^{a}± 0.31	5.15^{a}±0.24	304.90 ± 0.25^{c}
Mixed quinoa seeds	169.03^{a}±0.29	37.19^{c}± 0.40	3.64^{b}±0.26	317.43 ± 0.14^{b}

Means with different letters in a column are significantly different at the 0.05 level of significance.

Functional properties

Functional properties of colored quinoa seeds after poaching process as water uptake ratio (WUR) and volume increase (VI) are given in Figure 5. The water uptake ratio is an important parameter during cooking (Horigane et al, 2000). The results showed that there are no significant differences in the water uptake ratio among all poached colored quinoa seed samples. Notably, the poached black quinoa seed sample had the highest volume increase (1.658%) compared with the other samples which may be attributed to the higher crude fiber content in black quinoa seeds.

Total saponin content of colored quinoa seeds before and after poaching process

The saponin content of the colored quinoa seed varieties was measured in raw seeds also after soaking and poaching (Figure 6). In raw seeds, saponin levels ranged from 0.1783% to 0.3254% but showed a significant decrease after the soaking and poaching process, with values ranging between 0.022% and 0.06%. Among the studied varities, black quinoa seeds exhibited the highest saponin content in raw seeds also after soaking and poaching (0.3254% and 0.06 %, respectively). In contrast, red quinoa seeds recorded the lowest saponin content (0.1783% and 0.022%) in raw seeds as well as soaking and poaching, respectively. No statistically significant differences in saponin levels were observed between white and mixed quinoa seed. The variation in saponin content among quinoa varieties may be attributed to environmental, climatic, and genetic factors Rodríguez Gómez et al. (2021). Previous studies have reported that washing, soaking, and steaming processes effectively reduce saponin levels in quinoa, primarily due to the leaching of saponins from the seeds (Bhathal et al., 2015; Padmashree et al., 2019).

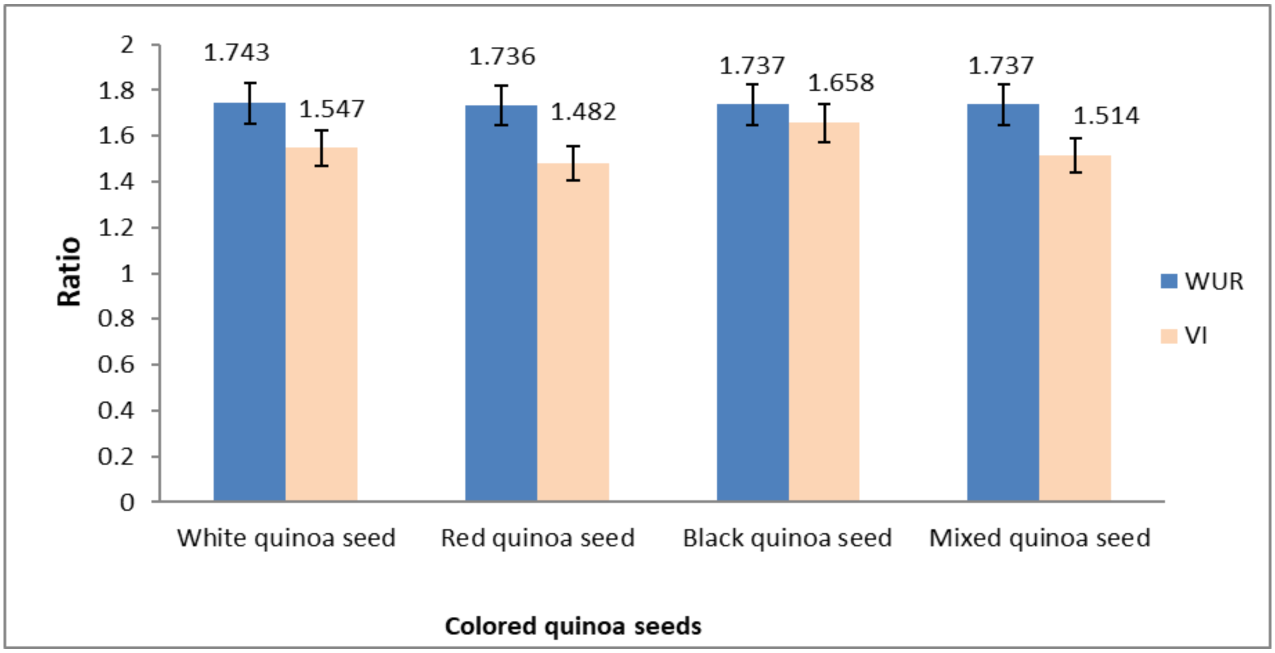

Figure 5. Water uptake ratio and Volume increase ratio after poaching process

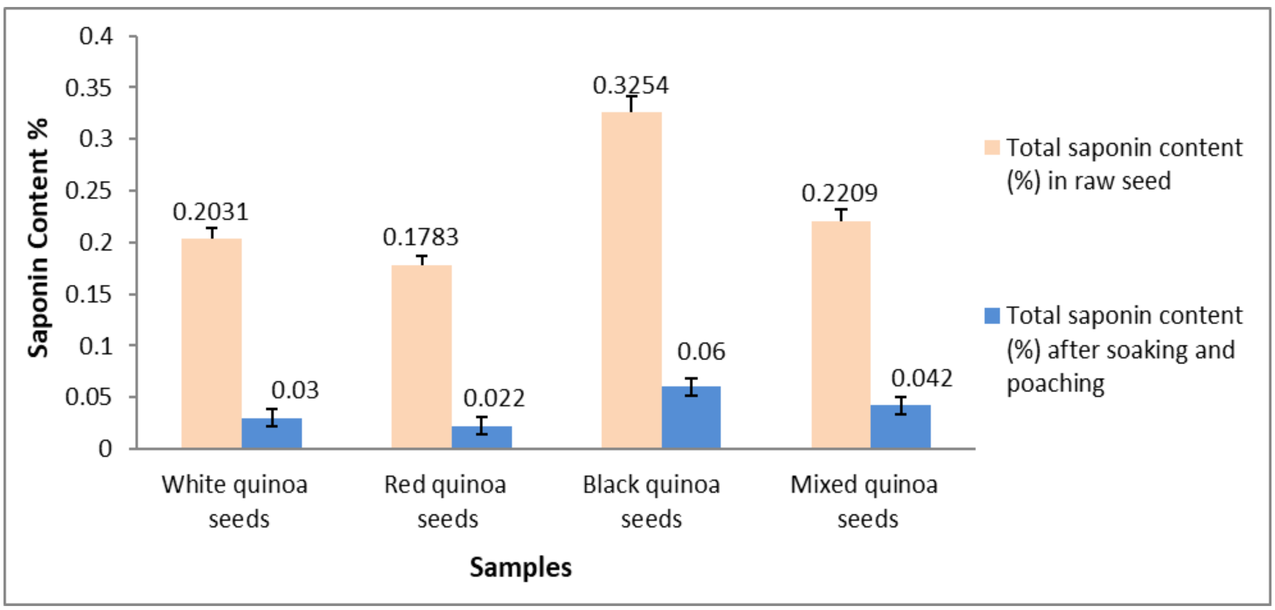

Figure 6. Total saponin content of colored quinoa seeds before and after soaking and poaching Process

Sensory evaluation

The sensory evaluation can improve a product's sensory quality to solve Consumers' problems related to food acceptance, and the final product must have an acceptable smell and taste. The sensory attributes of the control and calcium fortified poached quinoa samples are summarized in Table 5. The sensory evaluation indicated clear differences among quinoa varieties. White quinoa both control and calcium-fortified (w con and w forti) achieved the highest scores in color, taste, texture, and overall acceptability, followed by red and mixed quinoa. Black quinoa, particularly the calcium-fortified sample (B forti), received the lowest scores across most sensory attributes except for odor (7.6). Despite these differences, all samples were rated within the acceptable range, supporting their potential for consumer use. These findings agree with the importance of sensory properties in consumer acceptance as noted by Abeysinghe and Illeperuma (2006).

Table 5. Sensory evaluation of poached colored quinoa samples (control and calcium-fortified)

	Color	Taste	Odor	Texture	Overall acceptability
W Con	9.0 ± 0.25^{a}	8.85 ± 0.29^{a}	8.4 ± 0.45^{a}	8.85 ± 0.33^{a}	8.95 ± 0.15^{a}
W Forti	8.85 ± 0.35^{ab}	8.85 ± 0.45^{a}	8.2 ± 0.63^{ab}	8.90 ± 0.31^{a}	8.85 ± 0.33^{a}
R Con	8.55 ± 0.55^{b}	8.20 ± 0.48^{b}	8.5 ± 0.62^{a}	8.65 ± 0.47^{ab}	8.30 ± 0.58^{b}
R Forti	8.25 ± 0.47^{bc}	7.95 ± 0.43^{b}	8.15 ± 0.81^{ab}	8.20 ± 0.67^{bc}	8.10 ± 0.51^{bc}
B Con	7.80 ± 0.40^{c}	7.85 ± 0.66^{bc}	8.1 ± 0.69^{ab}	8.30 ± 0.75^{b}	7.80 ± 0.72^{c}
B Forti	7.85 ± 0.22^{c}	7.50 ± 0.57^{c}	7.6 ± 0.80^{b}	8.0 ± 0.90^{c}	7.60 ± 0.45^{c}
M Con	8.20 ± 0.33^{bc}	7.85 ± 0.47^{bc}	8.1 ± 0.73^{ab}	8.15 ± 0.85^{bc}	8.25 ± 0.71^{bc}
M Forti	8.25 ± 0.31^{bc}	7.90 ± 0.51^{bc}	7.9 ± 0.87^{ab}	8.20 ± 0.20^{bc}	8.0 ± 0.62^{bc}

W Con, R Con, B Con and M Con = Control of poached colored quinoa samples for white quinoa, red quinoa, black quinoa and mixed quinoa respectively; w Forti , R Forti , B Forti , and M Forti = calcium- Fortified poached quinoa samples for white quinoa, red quinoa, black quinoa and mixed quinoa respectively. Means with different letters in a column are significantly different at the 0.05 level of significance.

Chemical composition and mineral content of poached colored quinoa samples (control and calcium-fortified)

The chemical composition of calcium-fortified poached colored quinoa samples (on a wet basis) is presented in Table 6. The results clearly demonstrate the impact of calcium fortification, as fortified samples exhibited higher levels of moisture, ash, and calcium compared to their corresponding controls. Among all treatments, calcium-fortified poached mixed quinoa samples (M Forti) recorded the highest moisture content (87.82%), while the calcium-fortified poached white quinoa samples (W Forti) showed the highest ash content (3.92%). These increases may be attributed to the direct contribution of calcium fortification and the enhanced water-holding capacity of the fortified seeds. Similar findings were reported by Singh and Muthukumarappan (2008) and Khan et al. (2017). Red quinoa (control and fortified) exhibited the highest protein levels (5.30% and 5.08%, respectively) and also contained the highest fat content (4.84% and 4.31%, respectively). In addition, red quinoa samples showed the greatest zinc content, with 0.158mg/100 g in the control (R Con) and 0.125mg/100g in the fortified sample (R Forti). Black quinoa (B Con and B Forti) recorded the highest crude fiber content (5.02% and 5.03%, respectively). This genotype also showed the highest calcium concentration, reaching 185.10 mg/100 g in the fortified sample and 3.99mg/100g in the control, as well as the highest iron (Fe) content, measured at 0.525 mg/100g and 0.543mg/100g for B Forti and B Con, respectively. Mixed quinoa ranked second after black quinoa in terms of calcium and iron levels. As illustrated in Figure 7, the control samples of poached red quinoa (R Con) followed by black quinoa (B Con) exhibited the highest energy values, reaching 120.4 and 109.67kcal/100g, respectively, compared to the other quinoa samples.

Nutritional quality of poached colored quinoa samples (control and calcium-fortified)

The nutritional quality of samples was displayed in Table 7. According to Dietary Reference Intake (DRI, 2002/2005), The nutritional quality assessment for children (3–10 years) highlighted the distinct contributions of each quinoa variety. White quinoa (control) provided the highest carbohydrate 12.74% (based on 130 g/day) contribution to daily intake. Red quinoa (control and fortified) offered the greatest protein 18.92% and 18.14% per 100 g/day, respectively (calculated based on 28 g/day), and zinc contributions (2.82% and 2.23%, respectively) relative to the recommended daily intakes of 5.6 mg/day, while black quinoa (B Con and B Forti) supplied the highest calcium and iron values (0.57 & 26.44 %) of the daily intake (based on 700 mg/day) for Ca and (7.33% and 7.09%, respectively, relative to the recommended daily intake of 7.4 mg/day for Fe). Energy contributions were greatest in red, black and mixed quinoa (control samples) 6.02% , 5.48% and 5.32% respectively, (based on 2000 kcal/day). These findings emphasize the complementary nutritional roles of different colored quinoa varieties and agree with Dietary Reference Intakes (DRI, 2001; 2002/2005) and Torun (2005).

Table 6. Chemical composition (%) and mineral content (mg/100g) of poached quinoa samples (control and calcium-fortified) on wet bases

Parameter	Samples							
Chemical composition %	W Con	W Forti	R Con	R Forti	B Con	B Fort	M Con	M Forti
Moisture	73.26 ± 0.23^{e}	77.69 ±0.20^{b}	72.28 ±0.16^{f}	76.24 ±0.14^{c}	72.40 ± 0.05^{f}	76.03 ± 0.08^{c}	73.64 ± 0.08^{d}	78.82 ± 0.01^{a}
Protein	4.62 ± 0.01^{b}	4.45 ±0.01^{bc}	5.30 ± 0.07^{a}	5.08 ± 0.04 ^{ab}	4.28 ±0.03^{c}	4.16 ± 0.02^{cd}	4.12 ± 0.04^{cd}	4.03 ± 0.03^{e}
Fat	2.24 ±0.02^{d}	1.90 ±0.05^{e}	4.84 ±0.08^{a}	4.31 ± 0.11^{b}	4.11 ±0.12^{b}	3.87 ±0.02^{c}	4.11 ±0.13^{b}	3.73 ±0.14^{c}
Crude fiber	3.04 ± 0.17^{f}	2.99 ± 0.05^{f}	3.49 ± 0.22^{d}	3.30 ± 0.15^{e}	5.02 ± 0.11^{a}	5.03 ± 0.20^{a}	4.63 ± 0.17^{b}	4.37 ± 0.22^{c}
Ash	0.27 ±0.03^{de}	3.92 ±0.08^{a}	0.18 ± 0.01^{e}	3.81 ±0.02^{b}	0.30 ±0.03^{d}	3.81 ± 0.12^{b}	0.25 ^{de}0.03±	3.62 ^{c}05.±0
Total carbohydrate	16.57 ± 0.11^{a}	9.05± 0.22^{c}	13.91± 0.15^{b}	7.26 ±0.21^{d}	13.89 ± 0.16 ^{b}	7.10 ± 0.22^{d}	13.25± 0.11^{b}	5.43± 0.15^{e}
Mineral Content mg/100g								
Ca	2.846 ± 0.01^{g}	170.0 ±0.02^{d}	2.873 ±0.03^{f}	181.75 ±0.05^{b}	3.99 ±0.02^{e}	185.10 ±0.01^{a}	2.653 ±0.028^{h}	177.99 ±0.01^{c}
Fe	0.289 ±0.006^{g}	0.224 ± 0.03^{h}	0.455 ±0.003^{e}	0.416 ±0.04^{f}	0.543 ±0.05^{a}	0.525 ±0.005^{b}	0.511 ±0.03^{c}	0.501 ±0.01^{d}
Zn	0.088 ±0.005^{c}	0.061 ±0.05^{h}	0.158 ±0.002^{a}	0.125 ±0.004^{b}	0.071 ±0.03^{f}	0.065 ±0.005^{g}	0.086 ±0.004^{d}	0.082 ±0.01^{e}

W Con, R Con, B Con and M Con = Control of poached colored quinoa samples for white quinoa, red quinoa, black quinoa and mixed quinoa respectively ; w Forti , R Forti , B Forti , and M Forti = calcium- Fortified poached quinoa samples for white quinoa, red quinoa, black quinoa and mixed quinoa respectively. Means with different letters in a column are significantly different at the 0.05 level of significance..

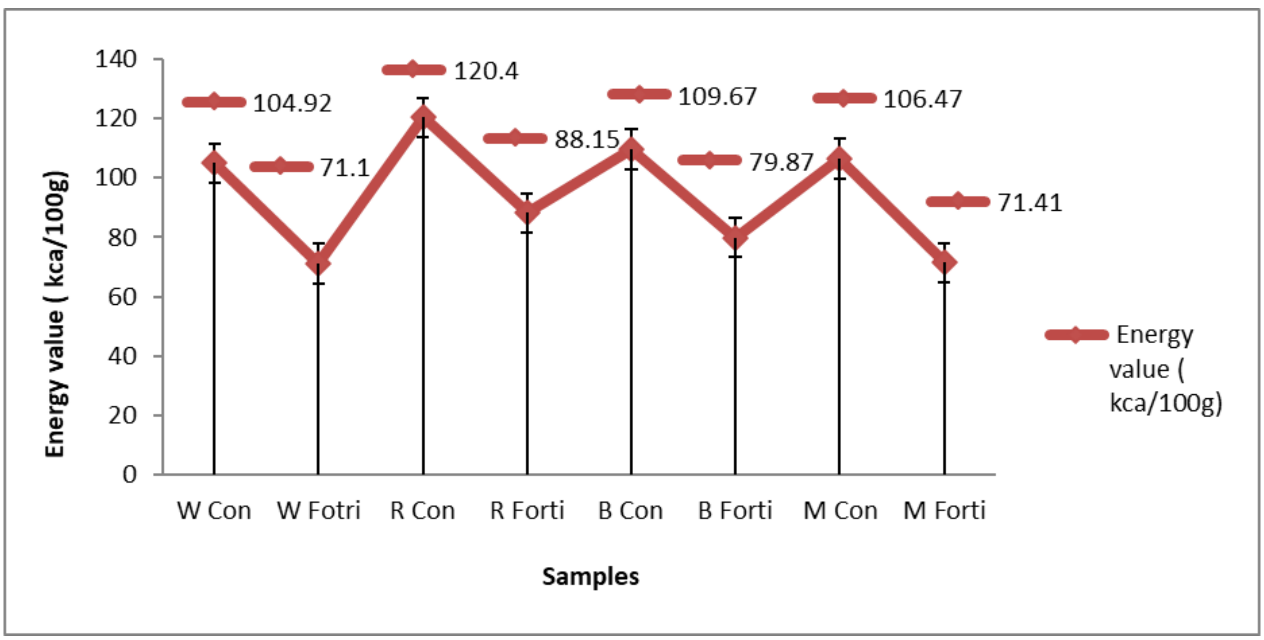

Figure 7. The energy value of poached colored quinoa samples (control and calcium-fortified)

W Con, R Con, B Con and M Con = Control of poached colored quinoa samples for white quinoa, red quinoa, black quinoa and mixed quinoa respectively ; w Forti , R Forti , B Forti , and M Forti = calcium- Fortified poached quinoa samples for white quinoa, red quinoa, black quinoa and mixed quinoa respectively. Means with different letters in a column are significantly different at the 0.05 level of significance.

Table 7. Nutritional quality of poached colored quinoa samples (control and calcium-fortified) for age (3-10) year for each 100g

DRI	DRI of protein / 100g	DRI of Carbohydrates /100g	DRI of energy /100g	DRI of Ca /100g	DRI of Fe /100g	DRI of Zn /100g
W Con	16.50	12.74	5.25	0.41	3.91	1.57
W Forti	15.89	6.96	3.56	24.29	3.03	1.09
R Con	18.92	10.70	6.02	0.41	6.14	2.82
R Forti	18.14	5.58	4.41	25.96	5.62	2.23
B Con	15.28	10.68	5.48	0.57	7.33	1.46
B Forti	14.85	5.46	3.99	26.44	7.09	1.16
M Con	14.71	10.19	5.32	0.38	6.90	1.53
M Forti	14.39	4.17	3.57	25.43	6.77	1.26
DRI**	Based on 28g/day	Based on 130g/day	Based on 2000 Kcal/day	Based on 700 mg/day	Based on 7.4mg /day	Based on 5.6mg/day

W Con, R Con, B Con and M Con = Control of poached colored quinoa samples for white quinoa, red quinoa, black quinoa and mixed quinoa respectively ; w Forti , R Forti , B Forti , and M Forti = calcium- Fortified poached quinoa samples for white quinoa, red quinoa, black quinoa and mixed quinoa respectively. Means with different letters in a column are significantly different at the 0.05 level of significance.

Color characteristics of poached colored quinoa samples (control and calcium-fortified)

Color plays a crucial role in a consumer's food choice and is essential to the overall appeal of a product. According to the results presented in Table 8, the lightness values (L*) varied significantly among all the samples, ranging from 40.42 to 56.16. All calcium -fortified poached quinoa samples exhibited a significant reduction in lightness values (L*) compared to their respective control samples. The highest lightness value (L*) was recorded in the control poached white quinoa (W Con), reaching 56.16, whereas the lowest (L*) was observed in the calcium-fortified poached black quinoa (B Forti) reached (40.42). Regarding redness (a*), values ranged from -0.54 to 4.33. The lowest redness value (-0.54) was found in the Control poached white quinoa (W Con). In contrast, the poached red quinoa samples for both control (R Con) and calcium-fortified (R Forti) exhibited a significant increase in redness (4.33 and 4.20, respectively). On the other hand, yellowness (b*) values significantly varied between 0.79 and 9.94. The highest yellowness value (b*) was 9.94 observed in the calcium-fortified poached white quinoa (W Forti). In contrast, (b*) values decreased in the poached black quinoa samples for both control (B Con) and calcium-fortified (B Forti) at 1.03 and 0.79 respectively.

Table 8. Color characteristics of poached colored quinoa samples (control and calcium-fortified)

samples	L*	a*	b*
W Con	56.16 ± 0.33^{a}	-0.54 ± 0.05^{e}	8.65 ± 0.10^{b}
W Forti	55.12 ± 0.21^{b}	-0.23 ± 0.08^{d}	9.94 ± 0.01^{a}
R Con	43.82 ± 0.01^{e}	4.33 ± 0.17^{a}	3.17 ± 0.15^{cd}
R Forti	42.52 ± 0.29^{f}	4.20 ± 0.09^{a}	2.91 ± 0.13^{d}
B Con	41.70 ± 0.17^{g}	2.01 ± 0.31^{b}	1.03 ± 0.02^{e}
B Forti	40.42 ± 0.13^{h}	1.4 ± 0.08^{c}	0.79 ± 0.06^{e}
M Con	48.07 ± 0.14^{c}	2.06 ± 0.06^{b}	3.12 ± 50.03^{cd}
M Forti	47.06 ± 0.22^{d}	1.40 ± 0.08^{c}	3.37 ± 0.18^{c}

W Con, R Con, B Con and M Con = Control of poached colored quinoa samples for white quinoa, red quinoa, black quinoa and mixed quinoa respectively ; w Forti , R Forti , B Forti , and M Forti = calcium- Fortified poached quinoa samples for white quinoa, red quinoa, black quinoa and mixed quinoa respectively. Means with different letters in a column are significantly different at the 0.05 level of significance

Table 8. Color characteristics of poached colored quinoa samples (control and calcium-fortified)

samples	L*	a*	b*
W Con	56.16± 0.33^{a}	-0.54±0.05^{e}	8.65±0.10^{b}
W Forti	55.12± 0.21^{b}	-0.23±0.08^{d}	9.94±0.01^{a}
R Con	43.82±0.01^{e}	4.33±0.17^{a}	3.17±0.15^{cd}
R Forti	42.52± 0.29^{f}	4.20±0.09^{a}	2.91±0.13^{d}
B Con	41.70±0.17^{g}	2.01±0.31^{b}	1.03±0.02^{e}
B Forti	40.42±0.13^{h}	1.4± 0.08^{c}	0.79±0.06^{e}
M Con	48.07±0.14^{c}	2.06±0.06^{b}	3.12±50.03^{cd}
M Forti	47.06±0.22^{d}	1.40±0.08 ^{c}	3.37±0.18^{c}

W Con, R Con, B Con and M Con = Control of poached colored quinoa samples for white quinoa, red quinoa, black quinoa and mixed quinoa respectively ; w Forti , R Forti , B Forti , and M Forti = calcium- Fortified poached quinoa samples for white quinoa, red quinoa, black quinoa and mixed quinoa respectively. Means with different letters in a column are significantly different at the 0.05 level of significance

pH of poached colored quinoa samples (control and calcium-fortified)

Monitoring pH during storage is a critical parameter for assessing shelf life and ensuring the quality of food products. Table 9 illustrates the pH levels of poached quinoa samples at zero time and after 15 days of storage at 5^{o}C. The mixed quinoa (control) M con exhibited the highest pH values at both zero time (4.64) and after storage (4.48), while red quinoa (control) recorded the lowest (4.33 and 4.23, respectively). A slight decrease in pH was observed across all poached quinoa samples after 15 days of refrigerated storage at 5°C, reflecting a gradual increased in acidity. Despite the decline, all pH values remained below the critical limit of 4.6, consistent with FDA guidelines (Carvalho dos Santos et al., 2023). The observed variation in pH can be attributed to both intrinsic and extrinsic factors. Intrinsic factors, such as the composition of the quinoa seeds and the breakdown of sugars that contribute to acidity, together with enzymatic activity, play an essential role. Extrinsic factors, including storage conditions, further influence pH changes through diverse chemical reactions, collectively, these factors are critical in maintaining product safety and stability (Abdelaali et al., 2024).

Table 9. Measure pH of poached colored quinoa samples (control and calcium-fortified)

Formulas	pH at zero time	pH after 15 days
W Con	4.35 ± 0.01 ^{f}	4.29 ± 0.25^{c}
W Forti	4.51 ± 0.12^{d}	4.31± 0.11^{d}
R Con	4.33 ± 0.011 ^{f}	4.23 ± 0.34^{e}
R Forti	4.53 ± 0.15^{d}	4.39 ± 0.0.22^{c}
B Con	4.57 ± 0.10^{c}	4.24 ± 0.15^{e}
B Forti	4.52 ± 0.09^{b}	4.44 ± 0.29^{b}
M Con	4.64 ± 0.11^{a}	4.48 ± 0.25^{a}
M Forti	4.42 ± 0.14^{e}	4.38 ± 0.13 ^{c}

W Con, R Con, B Con and M Con = Control of poached colored quinoa samples for white quinoa, red quinoa, black quinoa and mixed quinoa respectively ; w Forti , R Forti , B Forti , and M Forti = calcium- Fortified poached quinoa samples for white quinoa, red quinoa, black quinoa and mixed quinoa respectively. Means with different letters in a column are significantly different at the 0.05 level of significance.

Microbiological aspcts of poached colored quinoa samples (control and calcium-fortified)

Table 10. presents the microbial growth rate of poached colored quinoa samples stored under refrigerated conditions (5°C) for 15 days. At the initial time (zero storage time), the total bacterial counts in all samples ranged from non-detectable (ND) to 1×10 CFU/mL, while yeast and mold were not detected (ND). After 15 days of storage, both total bacterial counts and yeast and mold levels increased but they remained within the limits; the highest levels were recorded in the poached white quinoa control sample (W Con), reaching 1.9×10^2 CFU/mL for total bacterial counts and 1.5×10^2 CFU/mL for yeast and mold. According to CODEX STAN 247-2005, the total viable bacterial count in aseptic and pasteurized products should not exceed10^2 CFU/mL (100CFU/mL) at the end of their shelf life. The lowest yeast and mold levels were observed in the poached black quinoa sample of both the control (B Con) and calcium-fortified (B Forti), with counts of 1.0×10^2 and 1.10×10^2 CFU/mL, respectively, this reduction may be attributed to its had high antioxdent activity. These findings align with previous research by Fasoyiro et al. (2005) and Andrés et al. (2001). Moreover the relatively low microbial counts observed may be attributed to the low pH levels, which are below 4.6, as shown in Table 9, consistent with U.S. Food & Drug Administration (FDA) recommended that acidity is essential for inhibiting the growth of bacteria and the production of their toxins (Carvalho dos Santos et al., 2023). The pH is therefore a critical factor in microbial control because the lower the pH, the more energy a microorganism's cells require to maintain their medium near neutrality within the cells, reducing the energy available for growth and toxin release. (Matthews et al., 2017)

Table 10. Microbiological aspects of poached colored quinoa samples (control and calcium-fortified)

Formulas	Total count bacterial(cfu/L)		Yeast &mold(cfu/L)	
	Storage periods			
	Zero time	After 15 dayes	Zero time	After 15 dayes
W Con	1×10	1.9×10^2	ND	1.5×10^2
W Forti	ND	1.7×10^2	ND	1.46×10^2
R Con	1×10	1.5×10^2	ND	1.43×10^2
R Forti	ND	1.5×10^2	ND	1.41×10^2
B Con	ND	1.3×10^2	ND	1.0×10^2
B Forti	ND	1.4×10^2	ND	1.10×10^2
M Con	1×10	1.5×10^2	ND	1.30×10^2
M Forti	ND	1.4×10^2	ND	1.35×10^2

W Con, R Con, B Con and M Con = Control of poached colored quinoa samples for white quinoa, red quinoa, black quinoa and mixed quinoa respectively; w Forti , R Forti , B Forti , and M Forti = calcium- Fortified poached quinoa seeds for white quinoa, red quinoa, black quinoa and mixed quinoa respectively. Means with different letters in a column are significantly different at the 0.05

4. Conclusion

From the results obtained we can conclude that, Quinoa is regarded as a promising grain due to its nutritional profile. This study aimed to evaluate different colored quinoa seed varieties; white, red, black, and their mixtures. The results of this study highlight the nutritional and functional potential of colored quinoa seeds. White quinoa demonstrated the highest carbohydrate content and sensory acceptability among the varieties tested. In contrast, red and black quinoa varieties exhibited higher concentrations of bioactive compounds, including phenolics, antioxidants, carotenoids, and anthocyanins. Specifically, red quinoa contained elevated levels of protein, fat, and zinc, while black quinoa was richer in dietary fiber, calcium, and iron. Calcium fortification significantly enhanced the nutritional composition of the quinoa seeds without adversely affecting sensory properties or microbial safety. Furthermore, all treated and stored samples maintained acceptable pH levels and remained within safe microbial limits. This confirms the stability of calcium-fortified quinoa products, their potential for extended shelf life. Based on these findings, the study recommends combining these varieties to enhance their overall nutritional profile and functional health benefits. This approach may offer a promising strategy for developing nutrient-dense functional foods.

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