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Quality evolution of a standardized quinoa-based functional beverage during cold storage

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Abstract
The aim of study was to develop and evaluate a functional, lactose-free, gluten-free quinoa beverage formulated with natural fruit and spice extracts. White polished quinoa grains were processed to obtain quinoa milk, which was blended with carrot, beetroot, or papaya extracts to create three formulations (T1, T2, and T3). The beverages were pasteurized, bottled in glass containers, and stored at 4°C for 15 days. Physicochemical parameters (pH, viscosity, acidity, color, macronutrients, vitamins, minerals, and antioxidant activity), sensory attributes, and microbial quality were assessed at regular intervals. Results showed a gradual decline in pH, viscosity, starch, protein, fat, and antioxidant activity during storage, with a corresponding increase in acidity and reducing sugars. Minimal losses were observed in minerals and fiber. Sensory evaluation indicated high acceptability across all treatments, with slight reductions by day 15 but remaining within "liked very much" on the hedonic scale. Microbial counts remained within acceptable limits initially but increased by day 15. Overall, the study confirms that quinoa-based functional beverages offer strong nutritional potential, desirable sensory properties, and acceptable short-term storage stability, supporting their suitability as healthy alternatives for lactose-intolerant and gluten-sensitive consumers.

Keywords: Quinoa beverage**,** Functional food**,** Physicochemical properties**,** Sensory evaluation**,** Storage stability**,** Gluten-free and lactose-free

Introduction
Quinoa considered as functional food which provides a substitute for nations experiencing food poverty in the face of importance of expanding the invention of high-grade nutritionally balanced foods to feed the global peoples in the circumstance of environmental revolution. Thus, 2013 has been designated as the "International Year of Quinoa" by the UN General Assembly in honor of the Andean people's traditional ways of living in balance with the environment, which have allowed them to reserve quinoa in its regular form as nourishment for both existing and upcoming age groups [1].
An ancient crop with nutritional and health benefits, Quinoa (*Chenopodium quinoa*) is native to the Andes area of South America. Quinoa's primary carbohydrate content is 52–60% starch [2]. Quinoa's total dietary fiber content ranged from 2.6% to 10%, with 78% of insoluble fiber and 22% of soluble fiber. It has remarkable amount of protein content (12-20 %). The main protein content in quinoa is albumins (34%), globulins (36%) and with low prolamins (0.6–6.9%) (Dakhili *et al.,* 2019). Pseudo cereals are rich in important amino acids, including methionine, threonine, and lysine at 5.1–6.4%, which is considered as a limiting amino acid in certain grains and wheat (Vakevainen *et al.,* 2020). In comparison to ordinary cereals, quinoa seeds have higher concentrations of micronutrints (magnesium, iron, calcium, and zinc) and vitamins (B group, C and E). Quinoa is a great source of phytosterols (β-sitosterol), which are lipophilic substances that have hypocholesterolemic effects [3].
However, quinoa possesses within its pericarp (comprising 86%) certain anti-nutritional constituents, referred to as saponins (secondary metabolites), which impart a bitter flavor to the grain. These compounds can exhibit significant toxicity when consumed in excessive amounts; hence, they must be eliminated prior to ingestion. Research has indicated that saponins negatively influence the nutritional characteristics of quinoa by diminishing the absorption of proteins, starch digestibility, and the micronutrient (zinc, iron and magnesium) [4].
The concentration of saponins in quinoa can be markedly decreased through methods such as overnight soaking, washing, germination, and cooking. Quinoa seeds naturally contain bitter substances called saponins, which range from 0.1 to 5.0%. The quinoa seeds utilized in this investigation had a saponin level of 0.30 ±0.02%. Washing or water maceration is advised to eliminate saponins. In this investigation, saponins were eliminated by washing with tap water. The total saponin in soaked, washed and cooked quinoa was undetectable after desaponification [5].
Quinoa exhibits exceptional resilience to abiotic stressors and is characterized by its high nutritional profile, featuring a distinctive balance and elevated levels of nutrients, thus rendering it a vital crop for enhancing nutrition security and dietary adequacy which is cultivated as alternative food crop in water scarcity zone in india. This crop possesses the capacity to address global challenges associated with the rising world population, the impacts of phytoremediation, rectifying nutrient deficiencies, climate change, desalinization, and also mitigating poverty [6].
The prevalence of metabolic diseases such as type 2 diabetes, higher blood pressure, overweight, higher lipid profile, obesity, and nutrition intolerances like lactose intolerance, gluten allergy, aflotoxin allergy has increased, leaving those who suffer from these conditions with fewer food options that are occasionally insufficient to meet their bodies' nutritional requirements [7]. According to the

American Heart Association, sugar-sweetened and artificially flavored beverages are a key contributor to several metabolic diseases. Recognizing the need, this study objectives to examine the physico chemical characteristics, sensory qualities, and storage stability of the underutilized pseudo cereal *Chenopodium quinoa* while producing lactose- and gluten-free functional beverages with various natural flavors. Functional products made from quinoa, such as quinoa bars, flakes, pasta, and baked goods, have shown promise in treating conditions like celiac disease, obesity, hypertension, and cardiovascular disorders [8].

Beverages are thought to be the most promising category among the many new and innovative functional foods being researched or currently available on the market due to their convenience, ability to satisfy consumer preferences for beverage taste, flavour, packaging type and material used, packaging quality, total size based on beverage quantity, layers of packaging material used, shape, appearance, nutritional information and excellent potential to maintain desired nutrients and bioactive compounds. There are many different kinds of commercial functional beverages on the market today, and non-dairy beverages derived from cereals, pulses, millets, pseudo cereals are becoming more and more popular as vegetarianism grows. Minor cereals such as oats, legumes, and pseudo cereals (quinoa, buckwheat, and amaranth) have been studied as raw materials for creating functional beverages in addition to the more popular cereals [9]. Thus considering nutritional benefits pseudo cereal *i.e. Chenopodium quinoa* having greater potential to be used for the production of functional beverage.

Materials and methods

Raw materials

Worldwide, consumers prefers a increased purchase of high-quality and nutrition rich food items that are worth the price they pay. The quality of food goods on the market is reflected in the type of components and raw materials used. Purchasing required raw materials and packaging materials should be done in accordance with the quality standards that suppliers must meet [10].

The polished white quinoa seed varieties were procured from Kissan world tie-up farmer from Mandsaur, Madhya Pradesh. Carrot, beetroot, papaya, dry ginger, mint, palm gur, pepper, dry cardomon, salt were used for the preparation of functional beverages were purchased from the local market of Madurai city and food grade preservative (Potassium metabisulphite) were purchased in bulk from the local chemical stores in Madurai. Glass bottles (250 ml) are used as packaging materials for bottling of functional quinoa beverages as they are good from the aesthetic and hygienic point of view which was purchased from Ramana packaging, Madurai. The chemicals and reagents used for the study were either Analytical Reagent (AR) grade.

Standardization of functional beverage

According to FSSAI specification the addition of juice content is 10%, TSS is around 13° Brix and acidity is about 0.3% used for standardizing functional beverages. The white polished quinoa grains with different flavoring ingredients (carrot, beetroot, papaya, dry ginger, cardamom and pepper) added to increase the consumption quality of quinoa beverage

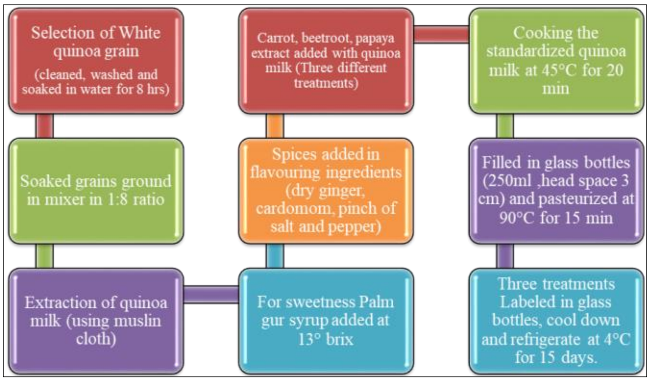

Fig 1: Preparation of functional beverage

Table 1: Functional beverages were prepared in three different formulations from extracted quinoa milk

Treatment	Ingredients (Natural flavor)							
	Quinoa seed milk (ml)	Water (ml)	Palm gur syrup (ml)	Carrot extract (ml)	Beetroot extract (ml)	Papaya pulp (ml)	Dry ginger and cardamom (g)	Salt & Pepper
T_1	20	60	10	10	-	-	0.5	-
T_2	20	60	10	-	10	-	-	0.2
T_3	20	60	10	-	-	10	-	-

T_1 T2 T3

Fig 2: Functional beverages prepared from extracted quinoa milk

Physicochemical and functional properties analysis of functional beverage

The physical property (pH, viscosity, color value and acidity), macronutrients (starch, reducing sugar, total sugar, protein, fat, fiber), vitamins (β carotene and Vitamin E), functional property (antioxidant activity) and minerals (Calcium and iron) changes in functional beverage were determined as follows.

The pH of the sample was estimated by the digital measurement method [11]. the viscosity instruction [12] and the Color measurements (L* a* b* values) of the quinoa grain was determined using a Hunter chromometer with the Lovibond RT Color software (Version 3.0) [13]. the acidity of the samples was estimated by the AOAC method [14].

Starch content of the sample was estimated using anthrone reagent [15]. Reducing sugar and total sugar of the sample was estimated by Dinitrosalicylic acid method (DNS) [16]. Protein was analyzed by the amount of nitrogen present in the sample by Micro kjeldhal method [17]. The fat content of the sample was estimated by the soxplus method [18]. The estimation of fiber was quantified in fiberplus [19].

Calcium can be determined volumetrically using permanganate solution [14]. The iron (mg/100 g) and vitamin E was calculated by the values on the iron and vitamin E standard graph respectively [17]. The β-Carotene of the sample was estimated colorimetrically [14]. The radical scavenging activity (antioxidant activity) of the samples was determined by the 2, 2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging assay [20].

Microbial analysis of functional beverage

The functional beverage was stored at 4°C to study the shelf life. Microbiological enumeration of bacteria, yeast, fungi and coliforms was recorded on 0, 7 and 15th day of storage period [21].

Organoleptic evaluation of functional beverage

The standardized raw and germinated quinoa beverage during storage was evaluated for organoleptic parameters (color, appearance, flavor, taste, consistency and overall acceptability) by a panel of 20 semi-trained judges using a score card with 9 point hedonic rating scale. The evaluation was carried out in the intervals of 3 days (0, 3, 6, 9, 12 and 14 days) for a storage period of 14 days [22].

Statistical analysis of functional beverage

The data were analyzed using WASP-Web Agri Stat Package 2.0, single factor ANOVA analysis done with completely randomized design (CRD) with p≤0.05 was performed to identify significant differences in all experimental parameters carried out in studies at triplicates. It was applied for the physicochemical, sensory attributes and functional property analysis of functional beverage (T_1, T2, and T_3) [23].

Results

Changes in the physicochemical and functional properties of the functional beverage

Customers around the world expect a steady supply of meals of superior quality. Food safety is more closely related to the composition of different food chemical and microbiological characteristics, whereas food quality can include elements like organoleptic characteristics, physical and functional properties, nutritional value, and consumer protection against adulteration.

The physical property (pH, viscosity, color value and acidity), macronutrients (starch, reducing sugar, total sugar, protein, fat, fiber), vitamins (β carotene and Vitamin E), functional property (antioxidant activity) and minerals (Calcium and iron) changes were observed in the functional beverage T_1, T2, and T_3 filled in glass bottles (to prevent the excess changes in physicochemical and functional value) during 15 days of storage study, refrigerate at 4°C are given in Table 2 and Figure. 2

Table 2: Changes in the physicochemical and functional properties of the functional beverage

Particulars (per 100 ml)	T_1		T_2		T_3		CV p(≤0.05) CD (0.05)	
	0 day	15th day	0 day	15th day	0 day	15th day	0 day	15th day
pH	6.74	3.09	6.68	3.04	6.54	3.01	2.65^{NS}	3.37^{NS}
Viscosity (cp)	17.77	14.23	17.64	14.11	17.82	14.14	3.53^{NS}	2.78^{NS}
Color value (L*)	36.52	36.35	35.42	35.36	33.49	33.32	1.87	1.32
(a*)	48.56	48.39	49.56	49.36	47.13	47.09	1.27	2.71^{NS}
(b*)	21.27	21.69	21.27	21.46	20.07	20.01	3.48^{NS}	3.42^{NS}
Acidity (%)	1.89	4.17	1.84	4.20	1.88	4.15	2.37^{NS}	1.85^{NS}
Starch (g)	33.84	30.22	33.75	30.20	33.70	30.24	2.07	1.01^{NS}
Reducing sugar (g)	2.65	5.86	2.52	5.72	2.59	5.70	2.56^{NS}	2.14^{NS}
Total Sugar (g)	9.58	6.99	9.59	6.94	9.46	6.88	0.758^{NS}	1.34^{NS}
Protein (g)	7.94	4.23	7.84	4.11	7.86	4.14	2.96^{NS}	3.34^{NS}
Fat (g)	3.79	1.09	3.72	1.05	3.93	1.04	2.89^{NS}	0.27
Fiber (g)	2.84	2.34	2.89	2.36	2.94	2.33	2.78^{NS}	2.54^{NS}
β carotene (mg)	39.78	39.35	36.84	36.46	31.62	31.33	1.38	1.85
Vitamin E (μg)	21.72	20.47	21.87	20.67	21.76	20.44	2.76^{NS}	2.85^{NS}
Antioxidant activity (GAE/mg)	9.26	8.13	9.29	8.16	9.21	8.14	3.03^{NS}	2.95^{NS}
Calcium (mg)	48.62	48.36	47.66	47.37	45.57	45.27	2.00	1.86
Iron (mg)	2.64	2.51	2.69	2.52	2.66	2.47	2.73	3.19

*CV- Coefficient of variance at 0.05 p value

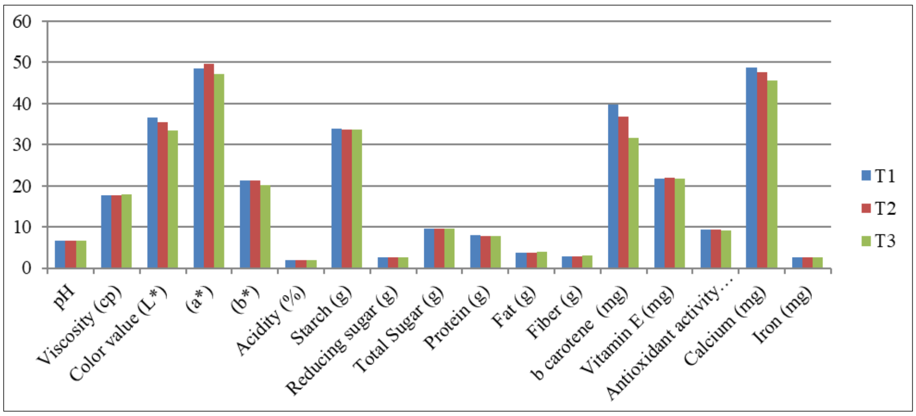

Fig 2: Changes in the physicochemical and functional properties of the functional beverage

The initial pH content of the beverage T_1, T_2, and T_3 was 6.74, 6.68 and 6.54 respectively which was drastically reduced at average of 3.05. Meanwhile the viscosity (cp) of three different treatments T_1 (17.77), T_2 (17.64), and T_3 (17.82) were considerably to become 14.16 cp on an average. The viscosity level depends upon the presence of starch content. Among the functional beverage the color value of T_1 exhibits higher level of lightness (L*36.52), positive redness (a* 48.56) and intensity of yellowness (b* 21.27), followed by T_2 (L*35.42, a*49.56 and b*21.57) and T_3 (L*33.49, a*47.13 and b*20.07). After 15 days of storage the color value on average is slightly reduced to L*35.01, a*48.28 and b*20.95. The acidity level (%/100 ml) initially were low T_1 (1.89), T_2 (1.84), and T_3 (1.88) which was significantly increased to 4.17 %/100 ml.

The statistical data revealed that the T_1, T_2, and T_3 were significantly different with each other. The pH of 6.89 in quinoa beverage [5]. the viscosity of quinoa beverage was between the range of 28.48 to 17.71 cp and total titratable acidity was 2.20%. After 28 days of storage study pH decreased to 3.86, acidity level increases to 9.50 % and viscosity decreases to 10.62 cp [24]. during the storage study fermentation process begins, the pH significantly decreases with increases in total acidity in the quinoa beverages [25].

The results are on par with the color value analysis [26] in the incorporation of quinoa extraction (10, 15 and 20 %) with pomegranate beverage shows significant difference was recorded among the different treatment (T_1, T_2, T_3, T_4 and T_5). By adding quinoa extract to sugar that was 15º Brix and 18º Brix, the L* value increased and varied from 15.72 to 24.69. The addition of quinoa extract was associated with a decline in the L* value of the pomegranate beverage at both 15% and 20% quinoa extract. In terms of numbers, T_1 had the greatest a* value (26.47). By adding quinoa extract, there were variations in the b* amongst the various pomegranate beverage treatments. Importantly, T_5 had the greatest b* value (2.19). During storage the reduction of the redness value of beverages occurs due to the natural pigment content of the quinoa, especially because has high phenolic components [27].

The T_1, T_2, and T_3 initial starch content (g/100 ml) was significantly 33.84, 33.75 and 33.70 respectively which were reduced to 30.22 g/100 ml. The reducing sugar level of three treatment T_1 (2.65), T_2 (2.52) and T_3 (2.59) was significantly increased to 5.76 g/100 ml. The functional beverage T_1, T_2, and T_3 had total sugar of 9.58, 9.59, 9.46 g/100 ml respectively which was reduced to 6.94 g/100 ml.

The novel quinoa milk. The HPLC-RID study revealed that quinoa milk had 9.7% total sugar and 5.0% starch, with glucose being the sole sugar detected. Compared to rice milk, quinoa milk has 32% more sugar and 15% more total carbohydrate. However, rice milk has a high glycemic index (79), while quinoa milk and soy milks, had a low glycemic index [28].

The protein content of three treatments initially was around 7.94, 7.84 and 7.86 g / 100 ml respectively which were reduced to 4.16. Likewise fat content (g / 100 ml) initially was 3.79 in T_1 followed by 3.72(T_2) and 3.93 (T_3). After 15 days of storage the fat content reduced to 1.06 respectively. Fiber content of standardized quinoa milk initially was 2.84, 2.89, and 2.94 g / 100 ml. After 15 days fiber was slightly reduced to 2.34 g / 100 ml.

The study of gluten free paste formulated by blending 10%, 20% and 50 % of quinoa flour with corn semolina flour and evaluated the highest protein content (8.8 g/100 g) in 50 % of quinoa flour blended gluten free paste. Fat (3.5g) and fiber (1.9g) content in 50 % gluten free paste when compared to 10 and 20 percent gluten free paste [27].

Among the functional beverage T_2 (39.78 mg/100 ml), exhibits higher level of β Carotene followed by T_1 (36.84 mg/100 ml), and T_3 (31.62 mg/100 ml) which were significantly reduced on an average of 35.71 mg/100 ml. Vitamin E content (µg/100 ml) in the functional beverage initially were 21.72, 21.87 and 21.76 respectively, after 15 days of storage life it was considerably reduced to 20.53 µg/100 ml.

The functional beverage had highest calcium (mg/100 ml) in T_1 (48.62) followed by T_2 47.66 and T_3 (45.57) which was reduced on average of 47.28 mg/100 ml. The initial level of iron content of the beverage T_1, T_2, and T_3 were 2.64, 2.69 and 2.66 mg/100 ml respectively. After 15 days of storage study they were slightly reduced to 2.66 mg/100 ml.

The quinoa based beverage powder (50%) developed along with Cushuro (*Nostoc commune*) cyanobacetrium (10%) rich in protein, calcium and iron. The result showed that powdered beverage (100g) presented an adequate amount of total sugar (9.33g), protein (14.36 %), fat (7.2 g), calcium (130.6 mg) and iron (4.0 mg) [29].

The initial level of antioxidant activity content (GAE mg/100 ml) of T_1, T_2, and T_3 were 9.26, 9.29 and 9.21. After 15 days of storage they were significantly reduced to average of 8.14 GAE mg/100 ml. the result was similar with the study conducted by Bhuvaneshwari *et al.,* 2023, the antioxidant activity of pomegranate beverages by incorporation of quinoa extract (15, 20 and 25 %) ranged between 9.54 and 9.81 GAE mg/100 ml. Compared to treatment T4, control II T5 exhibited 2.67 percent reduced antioxidant activity.

According to the author, the antioxidant activity of fruits and vegetables is mostly determined by the quantity of individual antioxidants or the combined action of antioxidants such as anthocyanins, ascorbic acid, and phenolic compounds. Because quinoa contains substances including polyphenols, phytosterols, and flavonoids that may have nutraceutical effects, quinoa extract added to pomegranate beverages showed the highest antioxidant activity [30].

Similarly, adding quinoa flour boosts the bread's antioxidant activity (8.9 GAE mg/100 ml) [31]. In addition, adding quinoa flour significantly improved the bread's DPPH radical scavenging capacity (10.15 GAE mg/100 ml), increasing it 1.38 times [32].

Changes in organoleptic properties of the functional beverage during storage

Sensory evaluation examines the organoleptic properties (color, appearance, texture, flavor, taste and smell) of the functional beverage through the senses (sight, smell, taste, touch and hearing) by the well trained panelists. They were evaluated standardized functional beverage (T_1, T_2, and T_3) organoleptic properties by using 9 point hedonic scale ranges from “like extremely to dislike extremely. Practically within 5 point hedonic scale value was considered as consumer acceptances.[33] the changes in organoleptic properties of the functional beverage T_1, T_2, and T_3 during storage were summarized in Table 3 and Figure. 3.

Table 3: Changes in organoleptic properties of the functional beverage during storage

Particulars	T_1		T_2		T_3		CV (0.05)	
	0 day	15th day	0 day	15th day	0 day	15th day	0 day	15th day
Color and appearance	8.9	8.5	8.9	8.3	8.9	8.4	2.37	2.28
Flavor	8.7	8.4	8.7	8.4	8.7	8.3	3.64	2.83
Consistency	8.7	8.3	8.7	8.3	8.7	8.4	2.34	2.55
Taste	8.5	8.4	8.5	8.4	8.5	8.4	3.50	2.87
Over all accepatability	8.7	8.4	8.7	8.4	8.7	8.4	3.10	2.45

*CV- Coefficient of variance at 0.05 p value

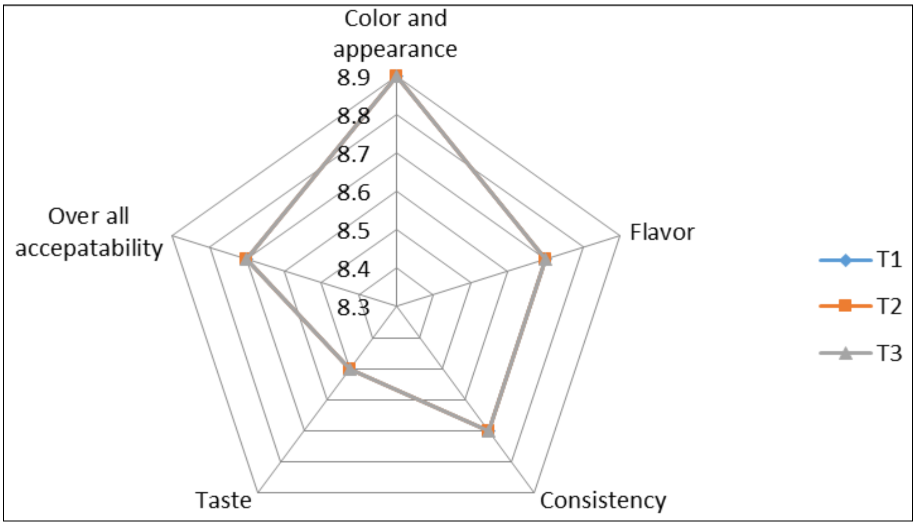

Fig 3: Changes in organoleptic properties of the functional beverage during storage

Among the functional beverage T_1, T_2, and T_3 on an average evaluated using 9-point hedonic scale were the color and appearance (8.9), flavor (8.7), consistency (8.7), Taste (8.5) and over all acceptability (8.7). The retention of organoleptic characteristics was higher in glass bottles. After 15 days of storage study the overall acceptability on an average was around 8.4 with significant loss in color, appearance, flavor, consistency and taste.

In the study incorporation of quinoa extraction with pomegranate beverage followed by biochemical and sensory attribute evaluation, determine the consumer preference of beverage evaluated using 9 point hedonic scale. The overall acceptability maximum score (8.42) was in T_1 8.14 (100 % pomegranate juice + sugar 15º Brix) which was on par with T_5 (100 % pomegranate juice + sugar 18ºBrix). There are no consistency (8.0) changes among all the treatment. The additions of quinoa extracts at different percentage 10, 15, and 20 % along with pomegranate juice have no changes in taste (8.17) and flavor (8.22). The color and appearance of T_5 scores maximum (8.42) followed by T_1 (8.39) [26].

Changes in microbial load of the functional beverage during storage

According to FSSAI specification the microbiological requirements for the functional beverage categories listed in the Table-4B (Food Safety Criteria Microbiological Standards (Process Hygiene Criteria) shows minimum to maximum limits in bacteria ($1x10^{6,7}$ CFU/g), fungi ($1x10^{2,4}$ CFU/g) yeast ($1x10^{2,4}$ CFU/g) and coliforms (0×10^2 CFU/g) in an acceptable manner in the market for final product. These are suggestive levels that, if exceeded, necessitate corrective measures to be done to ensure process hygiene.

Initially bacteria, fungi, yeast and coliforms count were not observed in the functional beverage T_1, T_2, and T_3 which were stored in glass bottles for 15 days of microbial study.

But later 15 days of storage the microbial load bacteria (5.5 x10^6), fungi (2.6 x10^4), yeast (2.47 x10^4) and coliforms (1.17 x10^2) was gradually increased in the entire treatment of functional beverage T_1, T_2, and T_3 which was exceeds the acceptable limit of FSSAI standard maximum value.

The viability of bacteria, fungi, yeasts and coliforms found throughout the storage study of quinoa beverage prepared by quinoa flour (QF) blend with chick pea flour (CF) (10, 25 and 50 %). All of the treatment shows nil viability of total plate count remained largely consistent throughout the course of the 50 days storage period. At the end of the storage study QF90-CF10 had the greatest total plate count (3 × 10^6 CFU/ml), followed by QF75-CF25 at around 2 × 10^6 CFU/ml. At the conclusion of the storage period, QF50-CF50 had the lowest total plate count, at about 1 × 10^6 CFU/ml. The QF50-CF50 blend's LAB slightly decreased during 0 and 10 days of storage. This might have to do with the early nutrient abundance during the storage phase, which makes starters and other bacteria or autochthonous LAB compete for resources [34].

Discussion

Based on the results of the study the following valid conclusions are drawn. The pasteurized quinoa milk with bland taste was flavored with fruits/vegetables/ natural flavor might increases the acceptability level among the panel of judges evaluated at 9-hedonic scale sensory evaluations. The bitterness of quinoa seed (saponin) was reduced by following process such as washing, soaking and cooking. The pasteurized functional beverage contains acceptable pH and acidity level which prevent fermentation of starch. In the developed functional beverage the shelf life of product maintained due to pasteurization and storage of beverage at refrigeration condition 4°C.

During storage period there was minimal nutrient loss occurred in glass bottle packed beverage and acceptable shelf life due to prevention of gas defecation and contamination. The pH level, viscosity, acidity, protein, fat, total sugar of functional beverage reduced. There was increase in reducing sugar due to conversion of non-reducing sugar (sucrose) into reducing sugar (glucose) in beverage. Negligible changes were seen in fiber and minerals (iron and calcium). But there is minimal changes occur in color value, β-carotene, antioxidant activity and vitamin E [35].

Thus the developed functional beverage made with raw and germinated quinoa milk can be accepted for all age group which gives fullness while drinking beverage. The nutritional and calorie rich functional beverage which may be recommended for lactose intolerance, supplements and celiac patient. The increase utilization of quinoa in processing may increase the value of crop. The technology develop occur with increase in the market potential commercially [36].

Conclusion

The present study successfully developed and standardized functional quinoa beverages using natural fruit and spice extracts, demonstrating strong potential as nutritious, gluten-free and lactose-free alternatives to conventional beverages. The formulated drinks exhibited desirable physicochemical characteristics, high sensory acceptability, and maintained satisfactory nutritional quality during refrigerated storage. Although gradual reductions in pH, viscosity, protein, fat, sugars, vitamins, and antioxidant activity occurred during 15 days of storage, these changes remained within acceptable limits. Mineral and fiber levels were largely stable, indicating good retention of essential nutrients. Sensory evaluation confirmed that all formulations were well accepted, with only minimal decline in color, flavor, and overall acceptability over time. While microbial counts increased by day 15, the products remained safe for short-term consumption under proper refrigeration. Overall, the study highlights quinoa's potential as a valuable ingredient for developing functional beverages that cater to health-conscious consumers and individuals with lactose intolerance, celiac disease, or special dietary needs. Enhancing utilization of quinoa in beverage processing can also support value addition and commercial opportunities for this emerging crop.

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Conflict of interest

The authors do not have any conflict of interest.

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