



Nutritional, Functional and Sensory Properties of Ready-to-Eat Chia and Quinoa Mix Enriched Low Amylose Rice Based Porridge Mixes

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Abstract

Ready-to-eat porridges are prepared from cereal flours. Pregelatinization of the starch component results in high hygroscopicity of porridge flours resulting in easy reconstitution. Chia and quinoa seeds are popular due to their health promoting nutritional composition and functionality. In this study, 10%, 15 % and 20% of a pregelatinized low amylose ready-to-eat rice flour was substituted with a 1:1 mixture of chia and quinoa seed flours. Analysis of significant difference between all the results was carried out by Duncan's multiple range test at a significance level of 0.05. Substitution significantly enhanced levels of proteins, dietary fibers, iron, calcium, potassium, sodium and zinc. Palmitic, stearic and oleic acids were proportionately higher than lesser significant changes in linoleic and alpha linolenic acid. Although thermal destruction caused marked reduction of total phenolic and flavonoid contents, relative rise in ferric and cupric ion reducing antioxidant potentials suggested probable formation of Maillard compounds with radical scavenging properties. Chia seed mucilage was found to play critical role in thickness and viscosity development in the optimally reconstituted porridges. Supporting results were also obtained from texture analysis of the porridges. However, the mucilage was observed to be sensitive to high cooking temperature resulting in lower cold paste viscosity in the rapid viscosity analysis study.



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Roasted aroma in porridges was more acknowledged. Substitution level of 20% gave an overall sensory score below the set acceptance level. Hence, porridge mixes prepared from the rice flour substituted up to 15% with the flour mix was sensorily acceptable, rich in macro and micronutrients and can serve as a therapeutic diet for infants, old-aged and patients with poor digestive systems.

Introduction

Porridge is primarily a cereal based breakfast dish consumed by people of all age groups. Because of its soft texture, easy digestibility and suitability to be used as a nutrient substituted meal for patients, porridge has been of special use while designing therapeutic diets.¹ Traditional methods of porridge making involves cooking of milled food grains in milk or water to its soft, semisolid consistency. A number of other additives are often added to enhance the taste of the final product. Coarsely broken rice (*Oryza sativa*, L.) and finer rice flour have been popularly used for porridge making.^{2,3} Polished rice grain contains up to 90% starch (db). Cooking results in gelatinization of starch and leaching out of soluble starch and protein components, leading to the viscous texture of porridge.⁴ Industrially processed, packaged instant dry porridge mixes are available in the market. Such products need simple reconstitution with water or milk to develop the consumable consistency. The principle behind this peculiar hydration capacity of the mixes is the presence of dehydrated pregelatinized starch in those, which has a tendency to absorb more water upon soaking.⁵ Hydrothermally treated low amylose *chokua* rice varieties with apparent amylose contents ranging between 7-20% are known to produce ready-to-eat (RTE) whole rice products like komal chaul and bhoja chaul.⁶ The hydrothermal processes primarily involving steaming and roasting result in pregelatinization of starch in these products. They do not require cooking and can be reconstituted to cooked-like texture and viscosity by hydration at room temperature. Therefore, flour of hydrothermally treated *chokua* rice could be considered ideal base flour to prepare dry porridge mixes. Uncontrolled partial replacement of the base flour with other functional flours containing components that structurally interact, result in altered properties of the final product and affect sensory attributes.⁷ Stability of phytochemicals and their bioactive potentials is another major factor in confirming nutritional properties of hydrothermally processed

food products. While heat labile compounds are denatured, certain Maillard compounds with antioxidant activities may form in such products.^{8,9}

Chia (*Salvia hispanica*) and quinoa (*Chenopodium quinoa* Willd) seeds deliver remarkable functional and bioactive properties. Chia being a rich source of dietary fiber (34.4g/100g), protein (16.54g/100g), minerals, and natural antioxidants, its oil contains about 83% polyunsaturated fatty acids (PUFA). Omega-3 fatty acids and omega-6 fatty acids constitute about 68% and 20% of the PUFA content.^{10,11} Chia seed mucilage is located on the outer layer of the seed walls and forms a weak gel with water. This tetrasaccharide is made up of β -D-xylopyranosyl, α -D-glucopyranosyl, and 4-O-methyl- α -D-glucopyranosyluronic acid.¹² Molecular, rheological and functional properties of the gel has been assessed by multiple authors for their applicability in restructured meat foods, edible films and fat replacer in bakery products.^{13,14,15,16} These reports indicate that the material has good binding properties and is remarkably thermostable when cooked or baked under atmospheric pressure. However, no report on the effect of high pressure cooking and roasting on its functional properties is available. Quinoa is a pseudo-cereal containing high quality protein, dietary fiber and antioxidants. The quinoa oil is also rich in essential fatty acids, namely linolenic and α -linolenic acid.¹⁷ Quinoa starch has similar shape (polygonal) and size (1-3 μ m) as rice starch and has a low amylose content, which is similar to *chokua* rice.¹⁸ Quinoa flour has been successfully substituted and studied in pastry and bakery products.^{19,20} Substitution of tef (*Eragrostis tef*) flour with quinoa flour resulted in sensorially acceptable injera flatbread product.²¹ In a recent research, Pereira *et al.* (2019) investigated on the nutritional differences between different red, black and white quinoa variants and reported differences in proteins, carbohydrates, oxalic acid, γ -tocopherol and total tocopherols content.²² The study reconfirmed that the grain is of nutritional excellence. Trigo *et al*

(2018) applied an ethanolic saponin-free extract of quinoa flour on mackerels as glazing agent.²³ The layer had oxidant species inhibitory effect as showed by lowered rate of free fatty acid formation in the frozen fishes. Both chia and quinoa are reported to have potential effects against several physiological disorders, namely inflammatory diseases, cancer, diabetes, hypertension, cardiovascular diseases and obesity.²⁴ Flours of both the seeds have been incorporated in a number of popular processed food matrices by partially replacing the primary ingredients. A few such foods are biscuits and cookies,²⁰ chip-like snack foods²⁵ and bread,^{16,26} where significant textural, nutritional and bioactive improvements were recorded after substitution. No report on substitution of the seeds or their flours in porridge mix is currently available. Developing any food product with potential health benefits require exhaustive analysis of its physical, physicochemical, nutritional and sensory properties. In this study, a chia and quinoa seed flour mix was substituted in *chokua* rice flour at three different substitution levels. Dry instant porridge mixes were prepared from them using two different hydrothermal techniques. The dry samples were thoroughly assessed for their water activity, physical properties, proximate and nutritional compositions, fatty acid content and profile and bioactive and antioxidant properties. Optimally hydrated porridges were studied for viscosity, texture and sensory properties.

Materials and Methods

Freshly harvested milled low amylose *chokua* variety rice (11.2% apparent amylose content) was procured from local farmers of Assam, India. Imported chia seeds cultivated in Peru and white variety quinoa seeds cultivated in Bolivia were purchased from the market. The grains were pulverized (Philips, India) and passed through a 210 μm sieve before storing at 4 °C in sealed polypropylene pouches. All the chemicals, reagents and media were procured from Himedia and Sigma-Aldrich.

Flour Mix Preparation

Chia and quinoa flours were exposed to 70% relative humidity for 4 hours at a room temperature (RT = 25 \pm 2 °C) in a relative humidity chamber (Cole-Parmer, India). The moisture equilibrated flours were then blended in 1:1 (w/w) ratio. This served as the standard mix and coded as CQS. Rice flour was

replaced by 10%, 15% and 20% with CQS flour and subjected to processing treatments.

Processing of Instant Dry Porridge Mixes

Each dry flour mix was divided into two portions and subjected to pregelatinization using steaming and roasting techniques. For steaming, 100 g dry flour mix was first mixed with 400 ml water and cooked at 100 °C for 5 minutes. The gelatinized paste was cooled at 4 °C for 24 hours. The semisolid gel settled at the bottom was collected by decanting the excess water, levelled (5 mm bed thickness), dried at 40 °C in a tray dryer to 12% moisture (wb), pulverized to obtain particle sizes of 100 – 240 μm and stored at 4 °C in sealed polypropylene pouches. The steam pregelatinized 'S' samples were coded as per the percentage of substitution as S10%, S15% and S20%. For roasting, 100 g flour mix was first moistened to 35% moisture content (wb) by sprinkling water and equilibrating for 2 hours. The moist flour mix was then roasted over a roasting pan with continuous mixing at 175 \pm 5 °C for 90 s, cooled at RT and adjusted to 12% moisture (wb) content by exposing to 70% RH. These roast pregelatinized 'R' samples were coded as R10%, R15% and R20% respectively. Similarly steamed and roasted rice flours served as controls and were coded as RS and RR, respectively.

Nutritional Characterization

Proximate Analysis

Standard protocols were used to determine moisture, crude protein, crude fat and ash contents of the flour samples. All values were expressed in percentage (wb). Total carbohydrate was calculated as the percentage difference in sample mass to the sum of the other components.

Carbohydrate (% , wb) = 100 – [Moisture (%) + Crude protein (%) + Crude fat (%) + Ash (%)]

Fiber Content

A total dietary fiber assay kit (Sigma–Aldrich, USA) was used to analyze the total dietary fiber (% , db) content of the control, standard and sample flours.

Minerals

Atomic absorption spectrophotometry (AAS, iCE 3000, Thermofisher, USA) was used to quantify iron (Fe), sodium (Na), calcium (Ca), potassium (K)

Table 1: Proximate composition (% db), total dietary fiber content (% wb) and mineral composition (mg/100g) of the control and porridge flour samples

	CQS	RS	S10%	S15%	S20%	RR	R10%	R15%	R20%
Moisture	7.83±0.99a	12.43±0.45c	11.97±0.38b	11.74±0.55b	11.51±0.39b	12.28±0.89c	11.89±0.33b	11.45±0.43b	11.29±0.51b
Carbohydrate	38.97±0.71a	78.4±0.89e	74.45±0.48d	72.48±0.43cd	70.51±0.19b	78.92±0.93e	74.49±0.38d	72.17±0.43cd	71.12±0.55cd
Protein	18.69±0.31e	7.47±0.45a	8.59±0.59bc	9.13±0.63cd	9.71±0.28d	7.62±0.82a	9.01±0.66cd	9.37±0.48d	9.35±0.38d
Fat	32.28±0.53e	0.21±0.38a	3.41±0.46b	5.02±0.27c	6.62±0.32d	0.24±0.38a	3.36±0.19b	5.39±0.22c	6.85±0.41d
Ash	1.24±0.07b	1.09±0.04a	1.10±0.06a	1.11±0.07a	1.12±0.05a	0.94±0.08a	1.04±0.02a	1.08±0.04a	0.98±0.04a
Dietary fiber	27.54±0.89e	0.31±0.77a	2.33±0.03b	4.91±0.01c	6.48±0.06d	0.28±0.08a	2.65±0.04b	4.99±0.05c	6.94±0.04d
Iron	12.92±0.94a	315.44±1.33g	284.29±2.10f	273.02±1.09d	259.33±1.75b	326.02±1.34h	279.38±2.02e	259.39±2.30bc	264.26±1.99c
Sodium	5.57±0.88a	574.61±0.93i	514.17±0.99g	481.84±0.39d	454.83±1.33c	559.21±1.54h	508.30±0.92f	494.54±1.09e	441.27±1.44b
Calcium	394.57±0.89a	856.27±1.36h	786.02±1.22f	774.53±0.38d	681.01±1.90b	864.69±1.43i	797.19±2.11g	777.10±1.98e	695.27±0.89c
Potassium	699.67±1.67h	342.34±1.39e	318.94±1.75c	379.39±1.67g	273.99±1.45a	348.93±1.22e	331.85±1.55d	356.57±1.62f	285.57±1.37b
Zinc	3.56±0.08a	107.38±1.34h	95.66±0.89e	97.27±1.04f	81.18±1.00b	100.32±0.69g	94.16±0.94de	93.27±1.12d	86.45±0.98c

Mean values with different letters following them are significantly different from one another ($P > 0.05$).

and zinc (Zn) in the samples. The samples were digested using nitric acid in a Multiwave Eco, Anton Paar (India) microwave-assisted digestion system (600 W, 15 min). Phosphorus was estimated using an established spectrophotometric technique.²⁷ The value for each element was expressed in milligrams per 100 g of sample.

Peroxide Value and Free Fatty Acid

Fat was extracted from the flours by a continuous chloroform extraction method.²⁸ For measuring peroxide value (PV, meq O₂/kg fat), extracted fat was mixed with a dilute acidic potassium iodide solution and titrated against a 0.1 M sodium thiosulfate using starch indicator. Liberated free fatty acid (FFA, % oleic acid by mass) was determined by titrating extracted fat with potassium hydroxide using a phenolphthalein indicator.²⁷

Fatty Acid Composition

Chloroform extracted oils from QSC and composite porridge mix flours were saponified and esterified using methanolic KOH and methanolic HCl solutions to form their methyl esters. They were then separated in a gas chromatography unit (7890A, Agilent Technologies, USA) fitted with a fused silica capillary column (HP-88, 100 m x 2.250 mm x 2.0 µm) and a flame ionization detector (FID). The temperature limits of the injector and the detector were 20 °C and 250 °C, respectively. By comparing with retention times of standard fatty acid methyl esters, fatty acid in the samples were identified. Quantity of each fatty acid was expressed as relative peak intensity in the chromatogram.

Bioactive Characterization

Ethanol extracts of bioactive compounds were obtained from the flour samples. For this, 1 g sample was mixed with 10 ml of 80% ethanol and agitated in a shaking incubator set at 25 °C for 3 hours. The extract was estimated for total phenolics (TPC), flavonoids (TFC) and cupric and ferric ion reducing antioxidant activities.

Total Phenol Content (TPC)

Briefly, to 100 µl of the ethanolic extract of flour, 2.9 ml deionised water, 0.5 ml Folin-Ciocalteu reagent (FCR) and 2.0 ml of 20% sodium carbonate were added and mixed well. The mixture was incubated at RT for 60 minutes before recording absorption at 760

nm in a UV-Vis spectrophotometer (Varian Cary 50, Agilent, USA) against a reagent blank. Using ferulic acid as standard, the results were expressed as ferulic acid equivalent per gram sample (µg FAE/g).²⁹

Total Flavonoid Content (TFC)

The method described by Dewanto et al (2002) was used to measure TFC in the extracts using quercetin standard. One milliliter of the extract was mixed with 0.3 ml of 5% (w/v) sodium nitrite solution. 0.3 ml of 10% AlCl₃ and 2 ml of 1 M NaOH were added after 5 and 6 minutes, respectively. The mixture was then diluted with 6.4 ml distilled water and vortexed for 1 min. Absorbance was noted at 510 nm against water blank and result expressed as quercetin equivalents per gram (µg QAE/g) of sample.³⁰

Cupric Reducing Antioxidant Capacity (CUPRAC)

0.1 mL extract was mixed with 1 ml each of CuCl₂ solution (1.0 x 10⁻² mol/l), neocuproine alcoholic solution (7.5 x 10⁻³ mol/l), a solution of ammonium acetate buffer (1 mol/l, pH 7.0) and 1 ml of distilled water and vortexed. Absorbance was recorded after 30 min at 450 nm against a reagent blank. Standard curve was prepared using trolox reagent (molar absorptivity = 1.67 x 10⁴ l/mol/ cm). Results were expressed as micromolar trolox equivalent per gram (µmol TE/g) of sample.³¹

Ferric Reducing Antioxidant Potential (FRAP)

Ferric reducing capacities of aqueous extracts of the samples (1:10 w/v) were determined using a commercial FRAP reagent [FeCl₃, TPTZ (2,4,6 tripyridyl-s-triazine) in acetate buffer (pH 3.6)]. To 100 µl of the extract, 3 ml of FRAP reagent was added. After 4 minutes, absorbance of the blue colored solution was measured at 593 nm against FRAP reagent blank. Results were expressed as micromolar trolox equivalents per gram (µmol TE/g) of sample.³²

Functional Characterization

Density and Porosity

Bulk (ρ_b) and True (ρ_t) densities of the flour samples were determined by previously described methods.³³ Porosity (ε) was determined from the relation

$$\varepsilon (\%) = [(\rho_t - \rho_b) / \rho_t] \times 100$$

Table 2: Peroxide value, free fatty acid content and fatty acid profile of oil extracted from control and porridge flour samples

	CQS	S10%	S15%	S20%	R10%	R15%	R20%
Peroxide value (meq O ₂ /kg)	2.16±0.04a	7.84±0.05b	11.25±0.09c	17.31±0.04d	11.32±0.03c	17.35±0.11d	21.23±0.06e
Free fatty acid (% oleic acid eq. mass)	1.36±0.03a	9.29±0.05b	14.23±0.04d	19.64±0.05f	11.36±0.05c	16.31±0.02e	23.10±0.08g
Myristic acid	0.01±0.00	ND	ND	ND	ND	ND	ND
Palmitic acid	2.23±0.05f	0.42±0.01a	0.56±0.07c	0.98±0.06e	0.47±0.06b	0.78±0.08d	1.12±0.04e
Stearic acid	1.10±0.05g	0.32±0.02a	0.46±0.03c	0.51±0.01d	0.44±0.02b	0.53±0.04e	0.62±0.03f
Oleic acid (ω -9)	2.62±0.04f	0.34±0.03b	0.56±0.06d	0.66±0.05e	0.23±0.02a	0.34±0.03b	0.41±0.02c
Linoleic acid (ω -6)	7.17±0.06g	1.33±0.05b	2.28±0.06d	2.99±0.09f	1.12±0.02a	2.15±0.04c	2.43±0.05e
Alpha linolenic acid (ω -3)	17.39±0.09g	3.01±0.05c	3.26±0.06d	4.32±0.04f	1.99±0.06a	2.54±0.07b	3.97±0.07e

Mean values with different letters following them are significantly different from one another ($P > 0.05$).

ND = Not Detected

Color Values

The CIE L* a* b* color values were determined using a color measurement spectrophotometer (Hunter Color-Lab, Ultrascan Vis). The hue (H*) and chroma (C*) values of each sample was determined by the following formulae.

$$H^* = \tan^{-1} (b^*/a^*)$$

$$C^* = [(a^*)^2 + (b^*)^2]^{1/2}$$

Water Activity (a_w)

Porridge flour samples were subjected to 80% relative humidity at RT for 30 minutes before subjecting to water activity (a_w) analysis using a water activity meter (Rotronic, Switzerland) fitted with HC2-AW-USB probe and connected to a computer with HW4-P-QUICK-Vx software for aw measurement.

Hydration Capacity

5 g flour (12% moisture, wb) was hydrated to saturation by soaking in 100 ml distilled water at RT for 12 hours. The slurry obtained was filtered through a nylon filter paper (0.22 μ m, Sigma-aldrich) to collect the residue. Moisture was removed by drying at 105 °C for 6 hours and the dried weight was measured. Hydration capacity (H, % db) was calculated using the formula

$$H (\%) = [(\text{Weight of hydrated mass} - \text{Weight of dried flour}) / \text{Weight of dried flour}] \times 100$$

Sediment Volume and Solubility

1 g (db) flour was added to 10 ml distilled water in a stoppered graduated measuring cylinder. The mixture was agitated after each 2 minutes till 60 minutes. The upper level of sediment was measured

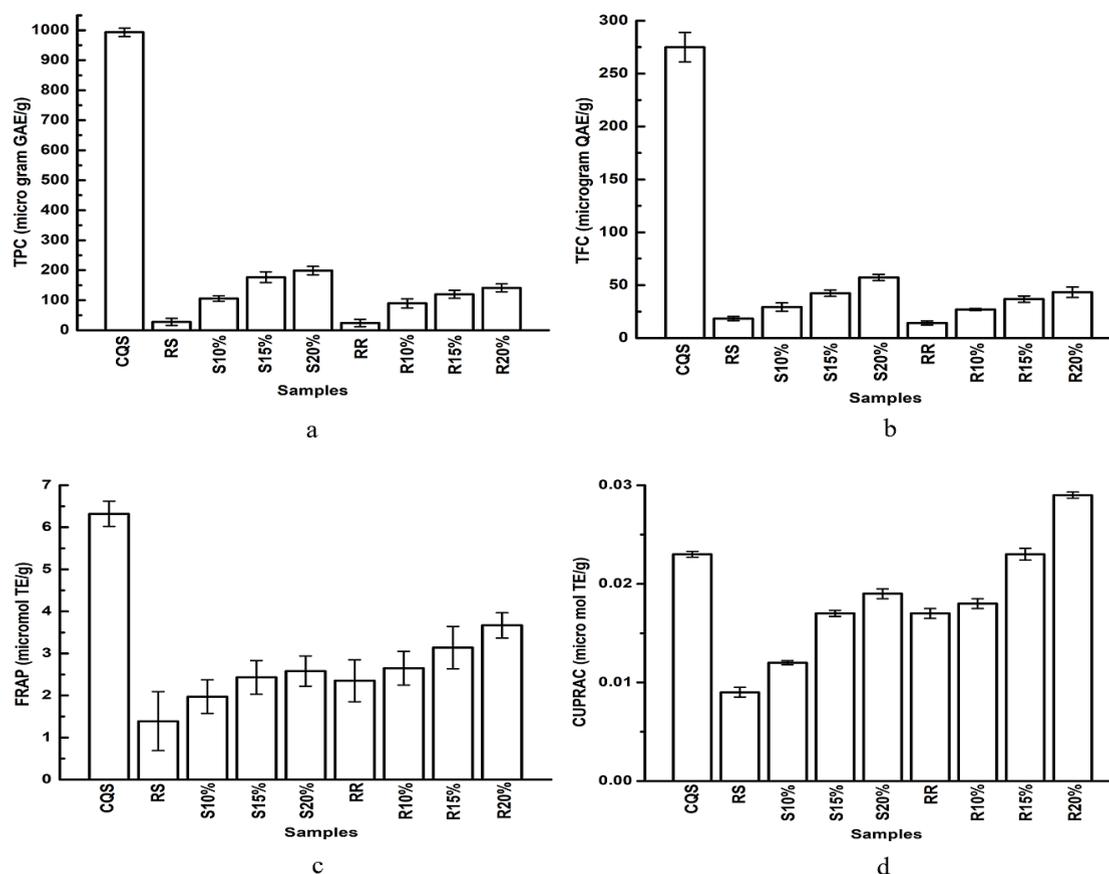


Fig. 1: Values of bioactive parameters, namely (a) Total Phenolic Content, (b) Total Flavonoid Content, (c) Ferric ion Reducing Antioxidant Potential, (d) Cupric ion Reducing Antioxidant Capacity of the control and porridge flour samples

as sediment volume (SV, ml). The supernatant obtained after centrifugation (1800 g, 10 minutes) was collected in a previously weighed desiccated glass petri dish and dried in a vacuum oven at 50 °C till constant weight. Solubility index (SI %, db) was measured as the percentage weight of the dried supernatant to the original dried flour sample.

$SI (\%) = [(Weight\ of\ dried\ petri\ dish - Weight\ of\ empty\ petri\ dish) / Dry\ weight\ of\ sample] \times 100$

Viscosity Analysis

Viscosity analysis of porridge was carried out both at RT and under cooking and cooling cycle. Porridge sample saturated to its previously measured hydration capacity was stored covered in a beaker for 10 minutes before subjecting to viscosity analysis at RT using a viscosity analyzer (HAAKE Viscotester, Thermo Scientific) fitted with a cylindrical probe (18 mm diameter) rotating at 100 rpm. Values were recorded at the 120th second of initiating operation. A rapid viscosity analyzer (RVA, Starchmaster 2, Newport Scientific Instruments) was used to determine the pasting profile of the flour slurry (12 %, w/w; 28 g total weight). As per a standard profile of the machine, after holding the samples at 50 °C for 1 min, temperature was raised to 95 °C at a rate of 12 °C/min, held at 95 °C for 2.40 min, cooled down to 50 °C at the rate of 11.25 °C/min and again hold at 50 °C for 1 min. Rotational speed of paddle was 160 rpm throughout the test, only after the initial 10 seconds when it was rotated at 960 rpm for efficient dispersion. Values of peak viscosity (PV), hot paste viscosity (HPV), cold paste viscosity (CPV), breakdown (BD) and setback (SB) were recorded.

Texture Analysis

The texture profiles of saturated porridge samples were determined by a back extrusion test carried out using a texture analyzer (TA.XT plus, Stable Microsystems, Surrey, UK) fitted with a 5 Kg load cell and a plunger-shaped probe of 40 mm diameter. The probe was moved at a speed of 1 mm/s to a penetration distance of 33 mm into each porridge sample and back. The maximum force value of the first peak, negative area of the graph and the ratio of areas under the two peaks were recorded as hardness (g), adhesiveness (g/s) and cohesiveness values, respectively.

Sensory Evaluation

Sensory evaluation of the porridge samples were carried out amongst 30 semi-trained panelists ranging from 18 to 21 years in age. The panelists had basic knowledge of sensory evaluation and primary idea on porridge and multigrain porridge mixes. For the analyses, porridges were freshly prepared by adding sufficient water to 100 g the four samples to previously calculated hydration capacities. 5 g sucrose was added and thoroughly mixed. The hydrated samples were evaluated for their appearance, texture, flavor, mouthfeel and overall acceptability on a 9-point hedonic rating scale anchored by 'dislike extremely' and 'like extremely'. The test was conducted after a 4 hours gap from breakfast. The evaluation procedure was explained to the panelists 20 minutes before carrying out the test. Samples were provided randomly to the panelists and sufficient time was given to avoid any misinterpretation. Rinsing of mouth with water after tasting each sample was ensured. Sensorially acceptable samples were identified based on the sensory scores obtained above the level of 6.

Statistical Analysis

All the analyses were carried out in triplicates and the mean (\pm standard deviation) values are reported. Statistical package for the social sciences (SPSS 11.5, USA) was used to perform Duncan's multiple range test (DMRT) at a significance level of 0.05 to determine the significant differences between the values of each parameter.

Results and Discussion

Proximate Analysis

The proximate compositions of the porridge flour samples are given in Table 1. The CQS flour was rich in protein, fat and ash content owing to high fat content of chia and high protein and ash content in both the seeds.²⁰ Substitution resulted in higher proportions of these proximate components in the composite porridge flour mixes than the control RS and RR samples. Reduction in total carbohydrate content was due to decreasing proportions of rice flour in these samples. Maillard reaction also causes marginal loss of carbohydrate and proteins in thermally processed samples by reacting to form melanoidin compounds.^{34,9} Starch content in rice contributed mostly to the carbohydrate content of all

flours. Presence of starch as the primary carbohydrate is necessary for attaining hygroscopicity through the principle of pregelatinization. No major change in proximate values was seen for the samples obtained from the two hydrothermal processes.

Fiber Content

Total dietary fiber content was notably higher in the CQS flour sample than the control processed rice flour samples (Table 1). This contributed to significant fiber content in the composite porridge mix flours. Both the processes were found to increase fiber levels in the composite samples and the effect was marginally higher in the roasted samples. Hydrothermal processing results in disruption of tissue structures and release of fiber components from the grain matrices. A number of reports on enhanced fiber content by this phenomenon using processes like steaming and extrusion have been reported.³⁵

Minerals

The CQS flour mixture was estimated to be rich in Ca and K while the processed rice flours were rich in Fe and Na. Substitution of the flour in the pregelatinized flour mixes substantially increased mineral content in them, as was also depicted by total ash content (Table 1). No effect of hydrothermal processing on mineral content values were observed. Substantially mineral enriched porridge mix flours with high concentrations of Fe, Na, Ca, and K were thereby obtained.

Peroxide Value and Free Fatty Acid

Processing resulted in marked increase in PV and FFA values as can be assessed by major difference in the values in CQS and the processed samples (Table 2). Roasting caused more severe hydrolysis and subsequent oxidation of liberated fatty acid showing higher values of both the parameters than in the steamed samples. Process temperature should be regulated to control fatty acid liberation. Lower oxidized entities in thermally processed products can be also attained by addition of antioxidant compounds in food formulations.³⁶ Quinoa seed possess natural antioxidants which could have an inhibitory effect in the relatively milder steam processed samples.³⁷

Fatty Acid Composition

The primary fatty acids in the oil extracted from QSC flour were palmitic, oleic, linolenic and alpha linolenic acids with traces of myristic acid (Table 2). Rice flour contained very limited amount of fat with no probable significant contribution to the fatty acid profiles of the flour mixes (Table 2). No peak for myristic acid was detected in the processed composite flour samples indicating probable thermal denaturation. Significant increase in palmitic, stearic and oleic acid with increasing CQS substitution level was observed. However, the increase in linoleic and alpha linolenic acid were not as significant as those. The trend was more prominent in the roasted samples. Decrease in PUFA (linoleic and linolenic acid) upon roasting was also reported by Vaidya and Choe (2011)³⁸ and Alasalvar et al (2010).³⁹ Thermal denaturation of triglycerides and subsequent oxidation are considered responsible for this drop in values.⁴⁰

Bioactive Characterization

Substitution induced bioactive values to the composite flours. TPC and TFC values increased, although to a lower extent when compared to the level of substitution (Figure 1). Thermal processing loss of phenolics and flavonoids in food substances is widely reported.⁴¹ Roasting exerted more severe effect on these native bioactive compounds than steaming. However, significantly higher values of CUPRAC and FRAP suggested probable formation of melanoidin compounds with active antioxidant properties in the high temperature roasted samples.^{8,9,42} Additionally, thermal processing could also release bound phenolics with antioxidant properties from complex tissues, thereby raising the overall antioxidant values.^{41,43} This change was less prominent in the steamed samples. Overall, the composite porridge mix flours had sufficient content of natural as well as process synthesized bioactive compounds in them.

Density and Porosity

Steamed RS and roasted RR flours showed lowest density and porosity values (Table 3). Incorporation of CQS flour with increasing proportions progressively increased porosity of the dry porridge mixes. This could be attributed to differences in particle shape and density in the rice and chia and quinoa flours.

Table 3: Bulk density, true density, porosity, water activity and CIE color parameter values of the control and porridge flour samples

	CQS	RS	S10%	S15%	S20%	RR	R10%	R15%	R20%
ρ_b (g/cm ³)	1.23±0.09c	1.01±0.02a	1.37±0.10de	1.39±0.08e	1.43±0.06f	1.13±0.05b	1.34±0.07de	1.39±0.09e	1.45±0.06f
ρ_t (g/cm ³)	1.68±0.05d	1.13±0.06a	1.54±0.09c	1.59±0.09c	1.67±0.06d	1.24±0.04b	1.72±0.07e	1.78±0.06e	1.85±0.08f
ε (%)	26.78±0.14f	10.61±0.25b	11.04±0.82b	12.57±0.65c	14.37±0.96d	8.87±0.19a	22.09±0.32e	21.91±0.74e	21.62±0.48e
aw	0.21±0.04a	0.45±0.05g	0.36±0.01e	0.32±0.10bc	0.31±0.03b	0.41±0.02f	0.34±0.02d	0.33±0.01c	0.31±0.04b
L*	29.43±0.98a	84.10±0.75h	49.51±0.39f	44.54±0.43de	42.18±1.19cd	68.42±0.98g	45.35±1.03e	41.43±0.88c	38.35±0.76b
a*	97.32±1.13i	3.56±0.88a	34.26±0.49c	38.12±0.98d	43.85±1.16f	19.24±0.89b	41.13±0.40e	46.37±0.99g	48.93±0.84h
b*	14.37±0.59e	2.69±0.05a	7.43±0.18bc	8.24±0.34bc	10.36±0.16d	16.24±0.46f	25.35±0.22g	27.46±1.00h	29.34±0.34i
H*	8.31±0.23a	36.65±0.76f	12.27±0.77b	12.13±0.49b	13.24±0.94c	40.14±0.09g	31.61±0.17e	30.63±0.42d	30.91±0.26d
C*	98.36±1.02i	4.42±0.09a	34.95±0.89c	38.93±0.48d	44.99±0.99e	25.17±0.49b	48.27±0.19f	53.84±1.04g	57.01±1.45h

Mean values with different letters following them are significantly different from one another (P > 0.05).

Table 4: Hydration properties of flour samples and viscosity parameter values of optimum hydrated porridge samples

	CQS	RS	S10%	S15%	S20%	RR	R10%	R15%	R20%
H (%)	128.53±1.39h	74.65±1.04a	83.33±0.98b	89.14±1.43c	96.77±0.49e	82.41±0.99b	94.83±0.34d	104.81±1.51f	114.32±0.88g
SV (mL)	3.44±0.09h	0.91±0.03a	1.47±0.04b	1.62±0.06c	1.75±0.03d	1.47±0.06b	1.97±0.06e	2.13±0.10f	2.44±0.04g
SI (%)	1.43±0.07c	1.12±0.06a	1.36.5±0.06b	1.55±0.08d	2.65±0.02h	1.44±0.03c	1.73±0.03e	1.86±0.02f	2.35±0.06g
Viscosity (at RT, cP)	67.33±0.98h	22.33±0.96b	32.44±0.29e	41.43±0.59f	49.29±0.55g	16.34±0.80a	24.32±0.19c	28.34±0.25d	32.44±0.51e
PV (cP)	3804.05±2.13i	1094.41±2.19c	1489.23±4.52e	2641.53±1.04g	3148.37±4.33h	707.31±3.10a	939.98±2.22b	1128.58±3.97d	1502.51±0.99f
HPV (cP)	3058.56±4.41h	910.45±3.26b	1534.17±5.66e	2793.77±3.19g	3306.40±4.75i	700.28±3.28a	1119.40±3.33c	1319.31±4.21d	1740.17±1.07f
CPV (cP)	4683.74±4.06i	1145.64±2.53a	1468.43±3.18e	2489.81±4.11g	2604.28±3.20h	1239.41±4.04d	1201.28±2.99b	1221.21±5.18c	1485.21±4.11f
BD (cP)	746.92±1.34i	184.76±1.56h	-45.16±2.04f	-152.50±1.09e	-158.92±2.19d	7.12±1.59g	-180.42±0.97c	-191.63±1.55b	-238.53±2.03a
SB (cP)	1625.25±2.19i	235.28±3.02g	-66.26±1.00e	-304.22±2.05b	-702.20±1.94a	539.32±1.15h	82.11±0.99f	-98.52±0.56d	-255.49±0.77c

Mean values with different letters following them are significantly different from one another (P > 0.05).

Effect of roasting on flour bed porosity was notably higher than that caused by steaming. Roasting caused rapid dehydration and major changes on particle surfaces resulting in altered packing properties.⁴⁴

Color Values

The lightness (L^*) values of samples decreased on substitution with dark QS flour (Table 3). Effect of roasting on color change was higher than steaming which may be attributed to Maillard browning. Marked increase in redness ($+a^*$) and yellowness ($+b^*$) values occurred after processing. Hue angle value (H^*) suggesting color intensity was highest for RR sample. Darkest CQS showed the lowest H^* value. However, level of substitution had limited effect on color intensity suggesting potential scope for further

increasing substitution levels. Starch gelatinization on steaming resulted in translucency of RS flours and its lowest chroma angle (C^*) value. Substitution with QS flour improved overall color purity of samples, as depicted by increased C^* for samples obtained from both the hydrothermal processes.

Water Activity (a_w)

The a_w values of food materials indicate the availability of free water, which can be used by microorganisms to grow and cause spoilage. Indirectly, it is determinant of the shelf life of a food product. CQS flour had markedly lower a_w than steamed and roasted rice flours suggesting lower free water availability in it (Table 3). Probably, higher amounts of soluble fibers in the flour resulted in rapid binding of water molecules in the former.⁴⁵

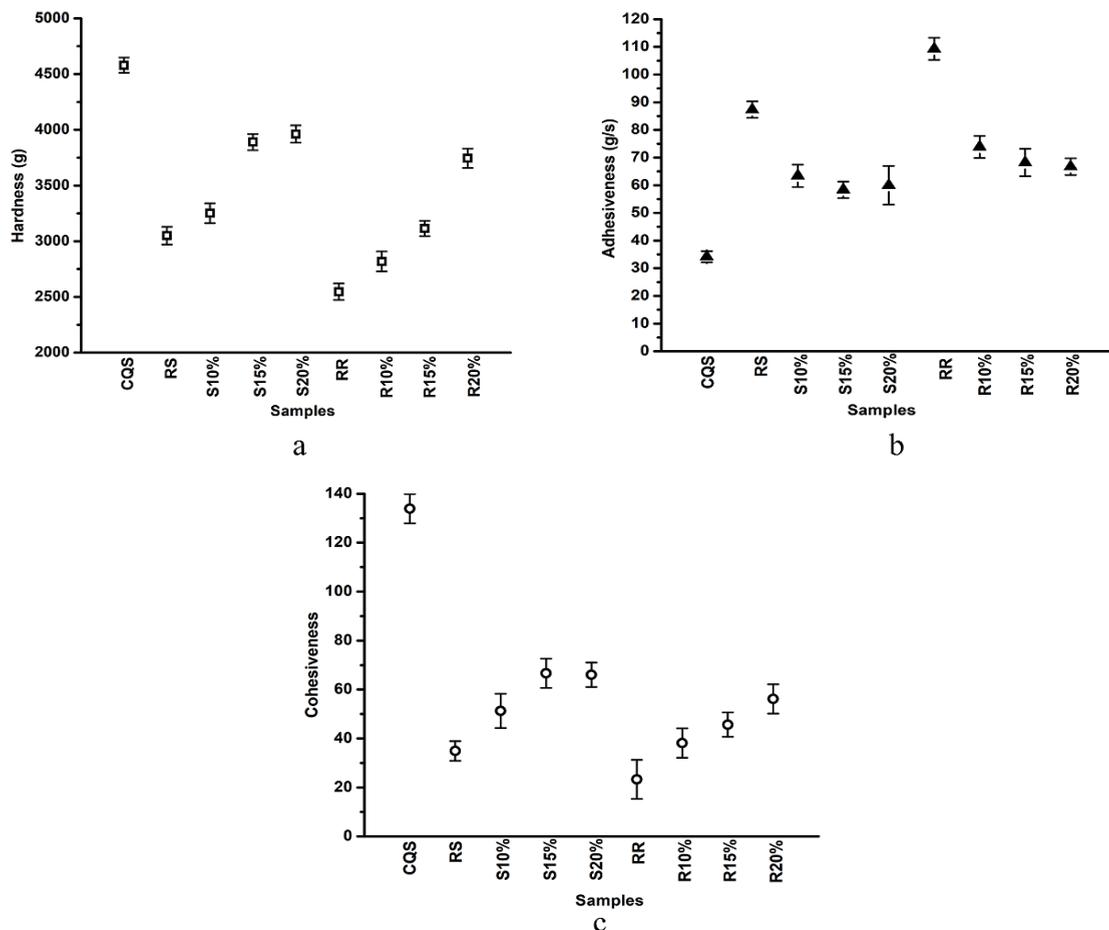


Fig. 2: Texture parameter values of optimum hydrated porridge samples (a) Hardness, (b) Adhesiveness, (c) Cohesiveness

Retrograding starches in the steamed and roasted samples also possess tendency to absorb moisture but with slower rate of water molecule entrapment due to slow occurrence of necessary conformational changes in the glycosidic chains.⁴⁶ Substitution with QS flour caused gradual lowering of aw in the flour samples. The results indicated that the substituted flours were more shelf stable than the standard steamed and roasted rice porridge flours.

Hydration Capacity

The CQS flour had very high hydration capacity (Table 4). Chia polysaccharides readily form a weak gel on soaking by absorbing high amount of water.⁴⁷ Quinoa flour is also known to have significant water uptake capacity.⁴⁸ Roasted rice flour RR showed higher hydration that steamed RS flour. Roasting results in gelatinization coupled with rapid dehydration, leading to high moisture uptake capacity in roasted cereal products. This effect is more prominent in low amylose and waxy starches.⁴⁹ Dietary fibers exposed through hydrothermal processing also possess enhanced hydration properties.³⁵ Substitution of rice flour with QS flour notably improved hydration capacities of dry porridge mix samples, which is favorable for reconstitution properties of the product. Roasted samples exhibited better hydration than steamed samples.

Sediment volume and solubility

Sediment volume and solubility index showed trends correlating with water uptake capacity of the flour samples. This value typically indicates the level of gelatinized starch in processed cereal flours.⁵⁰ Increasing values of SV with the level of substitution of QS suggested increasing sedimentation rate of the pregelatinized QS flours (Table 4). Roasted samples exhibited markedly higher SV than steamed samples with the same level of QS substitution. Occurrence of more gelatinized starch fractions in the former can be attributed to this difference. Thermal processing also increased soluble fractions causing gradual increase in solubility indices. Hydrothermal processing causes breakdown of complex biopolymers and form simpler oligomers with high solubility.⁵¹ Simple carbohydrates and proteins show ready digestibility as compared to their complex polymeric forms. This property is beneficial for infants, old-aged and patients with poor digestive system. Therefore, these pregelatinized porridge mixes can be developed as therapeutic diets for such age and health groups.

Viscosity Analysis

Optimum water saturated CQS flour showed the highest viscosity (67 cP) at room temperature (Table 4). Chia seed flour released its typical mucilage which formed gel with water, giving this high values

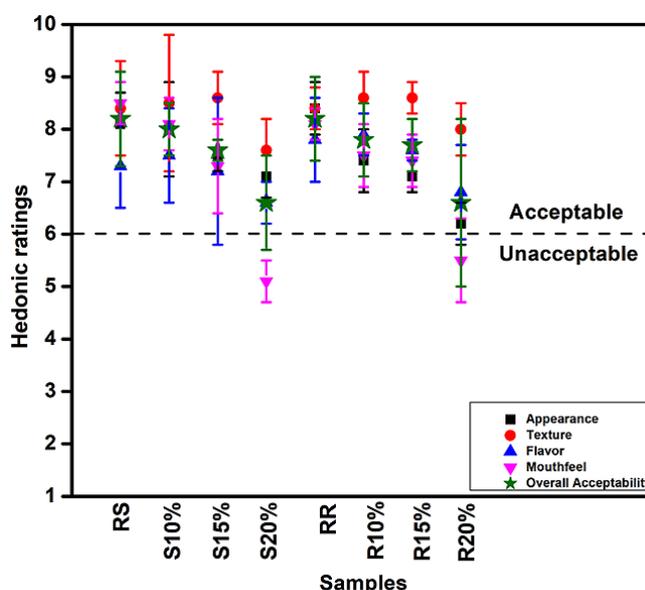


Fig. 3: Average hedonic ratings of different sensory parameters for optimum hydrated porridge samples

of viscosity. Steamed and roasted rice flours gave viscosity values of 22 cP and 16 cP, respectively. Roasting caused major breakdown of starch macromolecule resulting in lower viscosity in the slurries of RR, R10%, R15% and R20%. Roasted samples contain more gelatinized starch while steamed samples contain recrystallized fractions which may gain viscosity on further cooking. Addition of CQS increased slurry viscosity to several extents in both steamed and roasted porridge flour samples. Reduced rice flour proportion did not exert any prominent effect on the viscosity values. The values correlated with PV values obtained from the RVA, suggesting resistance of the gel to temperature rise till 95 °C. The CQS substituted samples showed no BD (negative values) and still increased viscosity to HPV values of 3306 cP and 1740 cP for S20% and R20%, respectively. Developing chia mucilage gel inhibited BD as typically occur during starch gelatinization. However, the CPV values for all substituted samples except R10% were lower than HPV values giving negative values of SB. R10% showed a similar trend with marginally lower viscosity loss and a SB of 82 cP. From this observation, it could be opined that the increasing gel integrity formed in the substituted sample pastes by chia mucilage gradually weakened and could not resist the shear exerted by the RVA paddle at the end of the heating-cooling temperature cycle.

Texture Analysis

Texture profile parameters of the optimally hydrated porridges are presented in Figure 2. Porridge prepared from CQS flour gave the highest hardness value (4578.33 g) due to the gel formed by chia mucilage. Hydrothermal processed rice flours, namely RS and RR gave hardness values of 3049.81 g and 2546.42 g respectively, indicating softer slurry formed by roasted samples with higher degree of molecular damage caused by higher intensity of process heat. Formation of simple leachable fractions on hydrothermal treatment resulted in significant adhesiveness in the two samples (87.32 g/s and 109.28 g/s). Similar observation was made by Wu *et al* (2017) with starch in cooked quinoa seeds.⁵² Hardness increased and adhesiveness decreased with increasing CQS concentration in the porridge samples. Increased cohesiveness were recorded and was found to be higher in the steam processed porridge samples (51.27 to 66.04) that the roasted samples (38.16 to 56.13).

Sensory Evaluation

The panelists did positively respond to the significant change in color of the porridge due to addition of the CQS flours at 15% and 20%, as indicated by lowering scores for appearance (Figure 3). However, there was improvement in texture on 10% and 15% substitution of flours in both steamed and roasted samples. Flavor improved for 10% substituted samples. The results indicate that the scores were higher for the roasted samples suggesting more acceptability of roasted aroma in the porridges by the panelists. Mouthfeel significantly dropped for 20% substituted samples. The overall acceptability was above 6.0 and could be considered satisfactory for all the composite porridge samples with lowest values exhibited by the S20% and R20%. A CQS flour substitution level up to 15% in the rice-based porridge could be considered to have sufficient sensorial acceptability.

Conclusion

Substitution levels of 10% and 15% of the CQS flour mix in the hydrothermally processed low amylose *chokua* rice flour resulted in sensorial acceptable ready-to-eat porridge mixes. These porridge mix products were significantly rich in protein, essential fatty acids, and minerals than normal rice porridge. Processing resulted in loss of natural phenolics and flavonoids, however maillard browning compounds with antioxidant activities were ascertained. Browning has limited effect on product acceptability. Chia seed mucilage played a direct functional role in deciding the viscosity and texture profiles of the porridge mixes, besides the general role of pregelatinized starch in them. The study indicated that chia seeds and mucilage can be studied for applicability as a potential natural food thickener. Sufficiently high water uptake was also recorded for the standardized samples. The dry mixes had low water activity, indicating long shelf stability when stored in water impermeable packages.

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Conflict of Interest

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