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Properties and Effect of Quinoa (*Chenopodium quinoa* Willd) Seed Germination on its Soluble Protein Content, Reducing Sugar, and the Preparation of a Porridge

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Abstract

This study assessed the characteristics of seeds from six varieties of Peruvian quinoa: INIA 415 Pasankalla (RPQ), INIA 420 Negra Collana (BNQ), Illpa INIA (WIQ), INIA 431 Altiplano (WAQ), INIA Salcedo (WSQ), and Kancolla (WKQ) during germination and prepared porridge from germinated seed flour. The seeds exhibited high germination capacity (≥95%), with notable radicle growth of WAQ and WSQ at 20 °C, while at 35 °C, there was no significant difference between cultivars, and growth was lower. The glutelin content of WKQ decreased over time, remaining stable for the other cultivars. The content of reducing sugars increased for all cultivars at both temperatures. At 20 °C, RPQ reached its highest level of reducing sugars first. Acidity increased over time, while pH decreased. WAQ and BNQ had the highest acidity levels after 84 h, while WAQ had the lowest pH value. Porridges prepared from spray-dried germinated quinoa seed porridge (GQP) of RPQ, as well as non-germinated quinoa seed porridge (NQP), showed no growth of pathogenic microorganisms. Both porridges had a similar proximate composition, although GQP had slightly higher protein content. Sensory evaluation did not indicate a significant difference, suggesting that the germination process did not affect the quality of this product.

Keywords

Germination, Soluble protein, Reducing sugar, Quinoa, Porridge

Introduction

The quinoa is an Andean pseudocereal, which can be cultivated both on the coast and at high altitude (3950 meters above sea level) [1]. Due to its nutritional composition [2], the exploration of specific cultivars for product development has been suggested. Various products based on non-germinated quinoa have been previously investigated and reported, including bakery products, instant soups [3], and porridges [4, 5].

Germination is a process used to modify, generally improving, the composition and characteristics of seed and grain nutrients. In this process, embryonic growth resumes after a resting phase. There is an active mobilization of reserves with macromolecules transformed into simpler and more accessible molecules for the embryo. Carbohydrates, proteins, lipids, phosphate, and nucleic acids are also mobilized; this process ends when the radicle has fully extended, regulated by pressure potential and due to the loosening of embryonic axis cell walls. This phenomenon is triggered when the seed has been placed in a favorable medium. Determining conditions of the medium include sufficient water supply, oxygen, and appropriate temperature [3]. Germination has been reported to enhance antioxidant activity in buckwheat [6], as well as improve the digestibility

of soy, pigeon pea, and quinoa proteins [7]. In Antezana et al. [8] it was shown that the germination effect depends on the quinoa variety or cultivar. Similarly, Vera et al. [9] identified increases in polyunsaturated fatty acid (PUFA) content for different quinoa cultivars during germination. This process has also been used to reduce the concentration of antinutritional or sensorially harmful compounds. Thus, Suárez-Estrella et al. [10] employed quinoa seed germination to decrease its saponin concentration, the main contributors to bitter taste and astringency. During germination, quality parameters to be monitored include radicle growth and reducing sugars. It has been previously reported that radicle growth also varies depending on the quinoa variety [3].

Germinated quinoa seeds constitute a product in itself, and the addition of additives to reduce its microbial load has been studied by Chacón and Montes [11]. Germinated seeds have also been used as raw material for other products, although they are still scarce. Jimenez et al. [12] developed baby purees based on a mixture including germinated and non-germinated quinoa and amaranth flours, indicating that protein digestibility improved with germination. Bhinder et al. [13] used germination as a process included in quinoa malting, also reporting the reducing sugar content.

To date, no systematic evaluation has examined multiple Peruvian quinoa cultivars under contrasting germination time and temperatures, especially their impact on key nutritional parameters such as soluble protein and reducing sugar levels. Given the growing global significance of quinoa and its potential in novel food products, it is essential to understand cultivar-specific responses to different germination conditions. This study fills that gap by comparing the germination behavior of six Peruvian quinoa cultivars at two temperatures and by evaluating how these differences affect the nutritional composition, microbiological safety, and sensory acceptance of a porridge made from spray-dried germinated quinoa.

Materials and Methods

Samples of quinoa seeds

Seeds of six colored quinoa cultivars were obtained from the Estación Experimental Agraria Illpa (Puno, Peru) of the Instituto Nacional de Innovación Agraria (INIA). The seeds of cultivar RPQ were red and those of cultivar BNQ were black, while those of cultivars WIQ, WAQ, WSQ and WKQ were white. Seeds were selected manually to remove impurities and broken seeds, according to the Peruvian standard NTP 205.062:2014 [14].

Saponin removal and disinfection

To remove the saponins, 250 g of each sample were weighed and manually washed with water in a 1:2 ratio (quinoa:water) at 37 °C for 20 min until there was no foam and the wash water was clear after rinsing.

The washed seeds were disinfected according to the procedure of de Ruíz [15]. They were first washed with 70% ethanol (v/v, volume/volume) for 1 min and then rinsed with distilled water three times. Finally, they were disinfected with 40.30 mmol/l NaClO for 10 s and rinsed with distilled water six times. The mold count was below the limit (104 colony-forming unit (CFU)/g) for dry *Chenopodium* seeds [16], confirming the efficiency of the disinfection process.

Germination procedure

The disinfected seeds were conditioned with distilled water in quantity according to equation 1 [17],

$$W = \left(\frac{100 - M_0}{100 - M_f} - 1\right) \times S \quad (1)$$

Where, W is the amount of water in g to be added to sample (S) in g with initial moisture (M_0) in % to reach target moisture (M_f) in %.

The initial moisture of the disinfected seeds of each cultivar was determined on a moisture analyzer (Sartorius MA 45, Sartorius AG, Göttingen, Germany). The target moisture content was 40% [17].

50 g of seeds from each cultivar were weighed and placed in 500 ml beakers with the corresponding amount of water W. The samples were incubated (Shel-Lab 1510E, Sheldom Manufacturing, OR, USA) at two temperatures (20 and 35 °C). Moisture was measured every 12 h with the analyzer. Water was added according to Equation 1 when the moisture value was below 40%. A portion of the samples was removed to test for soluble protein and reduce sugars after 6, 12, 18, 24, 36, 48, 60, 72, and 84 h of germination.

The germination capacity (%) of the cultivars was determined by soaking filter paper sheets with 3 ml of distilled water at the bottom of sterilized Petri dishes [18], adding 100 seeds to each plate before covering the plates and placing them in the incubator at 20 °C for 24 h [3]. The germination capacity was the number of seeds that grew radicle. Radicle growth was measured in triplicate with a Vernier caliper after 6, 12, 18, 24, 36, 48, 60, 60, 72, and 84 h of germination at 20 °C, and after 6, 12, 18, 24, and 36 h of germination at 35 °C.

Drying and packaging

The germinated seeds were dried in an oven (Binder GmbH, Tuttlingen, Germany) at 40 °C according to Amista and Tavano [19]. The final moisture content of the dried seeds was approximately 12% after 4 h. They were then packed in 100 ml Doy Pack PET bags with a 12 µm aluminum layer. The seed packs were kept in the shade at room temperature until analysis and processing.

Formulation and preparation of the porridge

1 kg of both germinated and non-germinated seeds from the selected cultivar of quinoa were washed and separately cooked at 100 °C for 20 min with tap water, along with 5 g of cinnamon and 5 g of cloves tied in a filter cloth. Then, the cloth with the spices was removed, the seeds were drained, and they were blended with boiled water in a 1:1 (w/w) ratio. The slurry was subsequently ground in a colloid mill (Fryma-Koruma MZ 100, Rheinfelden, Switzerland) with a 3.18 mm aperture size with boiled water in a 2:1 (w/w) ratio. It was then dried by atomization (Production Minor, GEA Group AG,

Düsseldorf, Germany) with an inlet temperature of 180 °C and an outlet temperature of 90 °C. The porridge formulation consisted of 64.64% pulverized quinoa, 19.39% skimmed milk powder, 15.95% ground sugar, and 0.01% powdered vanilla flavoring. Finally, the product was packaged in Doy Pack bags, labeling the porridge as based on GQP and NQP.

Analysis

Physical characteristics and saponin content (SP)

The average diameter of the seeds was determined by measuring the diameter of 100 seeds of each cultivar with a Vernier caliper. The weight of one thousand seeds was determined by weighing on a scale (ESJ 200, Adam Equipment Inc., Connecticut, USA) one thousand seeds of each cultivar. To determine the bulk density, a 250 ml graduated cylinder was filled with seeds and then the contents were weighed. The bulk density was expressed as kg/m^3. The weight of one thousand seeds and bulk density were determined in triplicate.

The SP was estimated by the afrosimetric method described by National Institute of Quality [14]. For this purpose, 0.5 g of sample (m) were placed in a 160 × 16 mm test tube and 5 ml of distilled water were added. The tube was capped and shaken vigorously for 30 s, followed by a 30 min pause. This cycle was repeated twice and then the tube was shaken again for 30 s and allowed to stand for 5 min. The height of the foam (h) was measured with a ruler (accuracy of 0.1 cm). The SP was estimated with equation 2.

$$SP = \frac{(0.64 \times h) - 0.104}{m \times 10} \quad (2)$$

Proximate analysis

The disinfected seeds were analyzed to determine their protein content (AOAC method 960.52 [20]), ash content [21], fat content (AOAC method 960.39 [20]), fiber content [22], moisture content [23], and carbohydrates (by difference). Proximate analysis was also conducted on the prepared porridges (GQP and NQP).

Acidity and pH

The acidity of the germinated seeds was determined by volumetric titration of 1 g of sample using 0.1 N NaOH and phenolphthalein, expressing the results as a percentage of sulfuric acid. The pH of the seeds was determined with a pH meter (Boeckel GmbH, Hamburg, Germany), for 5 g of ground samples mixed in 50 ml of distilled water.

Soluble protein concentration

The concentration of soluble proteins was determined by adapting the Bradford method as described by Kruger [24]. Samples of germinated or non-germinated seeds were processed (Thörben, Zlín, Czech Republic) for 20 s and then sieved through a 50-mesh sieve. Between 0.2 to 0.5 mg of sifted flour was weighed into 1.5 ml micro tubes, to which 1 ml of 0.1N NaOH was added, before being shaken for 3 s and allowed to stand for 30 min before being subsequently centrifuged at 2500 RPM for 5 min (PLC-012E, Gemmy Industrial Corp., Taiwan). A 100 µl aliquot was then extracted to which 1 ml of Bradford reagent was added, and absorbance was measured at 595 nm (SP-1104, Boyn Industrial Co., Hangzhou, PRC). The results were adjusted according to a standard curve prepared on the same day with bovine albumin. The determination was performed in triplicate.

Reducing sugar concentration

The determination of reducing sugar concentration was carried out following a modification of the method described by Miller [25]. The samples were ground in a processor for 20 s, then sieved (50 mesh sieve), before taking 1 g of the flour and placing it in a 125 ml conical flask with 100 ml of distilled water to be shaken for 30 min. It was then filtered (Whatman No. 1) onto a 100 ml volumetric flask, rinsing the conical flask with distilled water to reach the mark on the volumetric flask. An aliquot of 0.5 ml of this filtrate was taken and placed in a test tube to which 3 ml of DNS reagent was added and heated to boiling for 5 min, before adding 1 ml of sodium potassium tartrate solution. Finally, 15 ml of distilled water was added to each tube before mixing and cooling for 10 min to perform absorbance measurements at 550 nm. The results were adjusted with a blank of distilled water and a standard curve prepared with anhydrous glucose. The analysis was performed in triplicate.

Average particle size of the porridge

The mean size ($\overline{X}$, in µm) of the particles in the porridges (GQP and NQP) was determined using ASTM E11 stainless steel test sieves (No. 45, 50, 70, 89, 100, and 140) and 100 g of each porridge. It was determined using the following equation:

$$\overline{X} = \frac{\sum_{i=1}^{n}(M_i \times R_i)}{\sum_{i=1}^{n} R_i} \quad (3)$$

Where, M is the size corresponding to each sieve, in µm, and R is the percentage representing the fraction retained by each sieve.

Microbiological analysis

The porridges (GQP, NQP) were analyzed to determine the count of mesophilic aerobic bacteria (APC) (method 990.12 AOAC [20]), molds and yeasts (method 997.02 AOAC [20]), coliforms (ISO 4832 method [26]), *Staphylococcus aureus* (method 987.09 AOAC [20]), *Bacillus cereus* (method 980.31 AOAC [20]), and *Salmonella* sp. (method 967.25 AOAC [20]).

Sensorial evaluation

A hedonic scale test was conducted, adapted from Bustos [4] but using six trained judges. Samples were prepared with boiled water in a 1:5 (w/w) ratio. The characteristics of odor, flavor, consistency, strange flavors, and overall acceptability were evaluated on a scale from 1 - 5, ranging from "dislike very much" to "like very much".

Statistical analysis

The results were expressed as means values, followed by the standard deviation. Analyses of variance were performed using Tukey's HSD test in the statistical environment R (version 4.5.0) using the IDE RStudio (version 2025.05.0.496) and the agricolae package (version 1.3-7).

Results and Discussion

Characteristics of quinoa seeds

Physical characteristics and SP

The characteristics of the seeds of the six quinoa varieties are shown in table 1. The size and weight of one thousand seeds were similar to those reported by Apaza et al. [1] for the six cultivars, with BNQ having the smallest seeds and the lowest weight of one thousand seeds. Diaz-Valencia et al. [2] also reported that BNQ seeds had the smallest size compared to other red and white cultivars, while showing similar, albeit slightly lower, values of one thousand seed weight for RPQ, BNQ, and WSQ cultivars. BNQ and RPQ had significantly higher bulk density than the rest of the cultivars, but all the samples analyzed had lower bulk density than the Chilean cultivars grown in Argentina (550 - 740 kg/m^3) [27-30].

Apaza et al. [1] did not find saponins in the BNQ and RPQ cultivars, while Diaz-Valencia et al. [2] reported values of ≤ 0.01% for RPQ and ≤ 0.04% for BNQ and WSQ. Our results were slightly higher, except for WIQ, which was identical to that reported by Apaza et al. [1], and WKQ, which showed a lower SP.

Huang et al. [31] demonstrated that saponin levels decline during the initial phase of germination and then remain stable for up to 42 h, and because our porridge flour was produced from seeds germinated for only 12 h, measurement of SP in the germinated seed flour was not performed.

Proximal composition of seeds

The proximal composition of the seeds of the six quinoa varieties is shown in table 2. The protein, ash, and fat content of RPQ, BNQ, and WSQ were similar to those reported by Diaz-Valencia et al. [2]. All six cultivars presented values slightly lower than those reported by Apaza et al. [1], except in the case of WIQ, WAQ, and WKQ, which showed slightly higher fat content values. [9] also obtained higher lipid values for RPQ than for BNQ.

Germination characteristics

The germination capacity of the seeds was 98%, 96%, 98%, 97%, 99%, and 95% for RPQ, BNQ, WIQ, WAQ, WSQ, and WKQ, respectively. All these values were similar or even higher than those indicated in the certificates of each seed, especially in the case of WSQ (84%) and WKQ (85%). The growth of the radicle during the germination process is shown in table 3. Cultivars WAQ and WSQ had significantly faster initial growth at 20 °C compared to BNQ and WKQ, with RPQ and WIQ being intermediate. Moreover, from 18 h of germination onward, there was no significant difference in radicle length for the six cultivars. Apaza et al. [1] reported shorter radicle lengths after 24 h (0.84, 0.10, and 0.78 cm) and 72 h (2.05, 2.10, and 2.07 cm) for WKQ, WSQ, and RPQ, respectively, compared to our results. At 35 °C, there was no significant dif-

Table 1: Physical characteristics and SP of NQP.

Cultivar	Size (mm)	Weight of 1000 seeds (g)	Bulk density (kg/m^3)	SP (%)
RPQ	2.10 ± 0.19^a	3.77 ± 0.02^a	193.44 ± 0.67^a	0.02 ± 0.01^c
BNQ	1.66 ± 0.10^d	2.06 ± 0.03^e	197.10 ± 1.17^a	0.02 ± 0.01^c
WIQ	2.00 ± 0.19^b	3.45 ± 0.06^b	183.53 ± 2.39^c	0.02 ± 0.02^c
WAQ	2.03 ± 0.25^{ab}	3.16 ± 0.06^c	188.38 ± 0.84^b	0.62 ± 0.02^a
WSQ	1.97 ± 0.19^b	3.16 ± 0.07^c	178.41 ± 1.74^d	0.06 ± 0.02^b
WKQ	1.88 ± 0.13^c	2.62 ± 0.04^d	176.30 ± 1.32^d	0.01 ± 0.01^c

Note: Different superscripts letters in the same column indicate significant difference between means ($p < 0.05$).

Table 2: Proximal composition (% wb) of NQP.

Cultivar	Moisture	Protein	Fat	Ashes	Fiber	Carbohydrates
RPQ	10.21	14.03	6.76	2.18	4.74	62.08
BNQ	9.69	12.62	5.78	2.33	9.05	60.53
WIQ	8.47	13.57	5.39	2.10	2.19	68.28
WAQ	7.45	13.28	6.20	2.23	1.13	69.71
WSQ	8.59	13.27	4.96	2.19	4.27	66.72
WKQ	8.00	12.78	6.26	2.21	1.79	68.69

Table 3: Radicle growth of different quinoa varieties over time.

Time (h)	Radicle length (cm) during germination at 20 °C					
	RPQ	BNQ	WIQ	WAQ	WSQ	WKQ
6	0.17 ± 0.09^{ab}	0.00 ± 0.00^b	0.19 ± 0.14^{ab}	0.23 ± 0.07^a	0.21 ± 0.04^a	0.00 ± 0.00^b
12	0.44 ± 0.16^{ab}	0.29 ± 0.13^b	0.52 ± 0.15^{ab}	0.78 ± 0.22^a	0.55 ± 0.16^{ab}	0.42 ± 0.11^{ab}
18	0.84 ± 0.31^a	0.68 ± 0.35^a	0.83 ± 0.24^a	1.11 ± 0.29^a	0.77 ± 0.29^a	0.64 ± 0.19^a
24	1.23 ± 0.34^a	1.20 ± 0.36^a	1.24 ± 0.55^a	1.32 ± 0.39^a	1.34 ± 0.55^a	1.30 ± 0.38^a
36	1.68 ± 0.49^a	1.44 ± 0.56^a	1.66 ± 0.67^a	1.89 ± 0.67^a	1.73 ± 0.87^a	1.40 ± 0.51^a
48	2.76 ± 0.77^a	2.29 ± 0.52^a	2.26 ± 0.54^a	2.43 ± 0.56^a	2.43 ± 1.06^a	1.97 ± 0.62^a
60	2.72 ± 0.79^a	2.52 ± 0.65^a	2.99 ± 0.68^a	2.00 ± 0.80^a	3.61 ± 0.69^a	2.07 ± 0.72^a
72	4.03 ± 1.10^a	3.05 ± 0.79^a	2.85 ± 0.81^a	4.56 ± 1.41^a	4.61 ± 1.30^a	2.94 ± 0.79^a
84	4.05 ± 1.25^a	3.70 ± 0.90^a	3.40 ± 1.06^a	2.99 ± 0.88^a	4.35 ± 1.13^a	2.46 ± 0.66^a
Radicle length (cm) during germination at 35 °C						
6	0.12 ± 0.14^a	0.00 ± 0.00^a	0.00 ± 0.09^a	0.09 ± 0.12^a	0.07 ± 0.09^a	0.00 ± 0.00^a
12	0.42 ± 0.14^a	0.32 ± 0.11^a	0.63 ± 0.15^a	0.39 ± 0.11^a	0.54 ± 0.15^a	0.40 ± 0.15^a
24	0.75 ± 0.29^a	0.76 ± 0.29^a	0.87 ± 0.34^a	0.80 ± 0.36^a	0.83 ± 0.26^a	0.62 ± 0.24^a
36	1.10 ± 0.36^a	1.36 ± 0.29^a	1.36 ± 0.34^a	1.33 ± 0.48^a	1.47 ± 0.47^a	1.11 ± 0.27^a
48	1.53 ± 0.39^a	2.03 ± 0.58^a	1.85 ± 0.37^a	1.47 ± 0.29^a	2.09 ± 0.66^a	1.38 ± 0.40^a

Note: Different superscripts letters in the same row indicate significant difference between means ($p < 0.05$).

ference in radicle growth between cultivars for each measured time, but it was observed to be lower than that measured at 20 °C. After 48 h, the germinated samples at 35 °C had a radicle length of 1.38 - 2.09 cm, while at 20 °C the range was higher, from 1.97 to 2.76 cm. Therefore, higher temperatures would delay and reduce radicle growth. However, the results from Apaza et al. [1] were even lower than those showed in table 3 at 35 °C for WKQ, WSQ, and RPQ.

Soureshjani et al. [32] reported maximum germination temperatures of 33.6 - 34.9 °C for two South American quinoa varieties. In the present study, which tested even higher temperatures, radicle growth still occurred. The same authors identified optimum germination temperatures of 21.8 - 21.9 °C, closely aligning with the lower temperature (25 °C) we used. These findings confirm that germination temperatures above approximately 33 °C result in slower radicle growth.

Effect of germination

Soluble and total protein content

The variation in the content of soluble proteins (glutelin's) for the different quinoa cultivars under the two germination temperatures is shown in figure 1. The fraction they initially represented with respect to the total protein was 32.04%, 27.77%, 29.96%, 32.12%, 32.18%, and 32.67% for RPQ, BNQ, WIQ, WAQ, WSQ, and WKQ, respectively. This narrow range coincides with what was reported by Mufari et al. [27] for 9 quinoa cultivars (20.83 - 28.19%), although our values were higher.

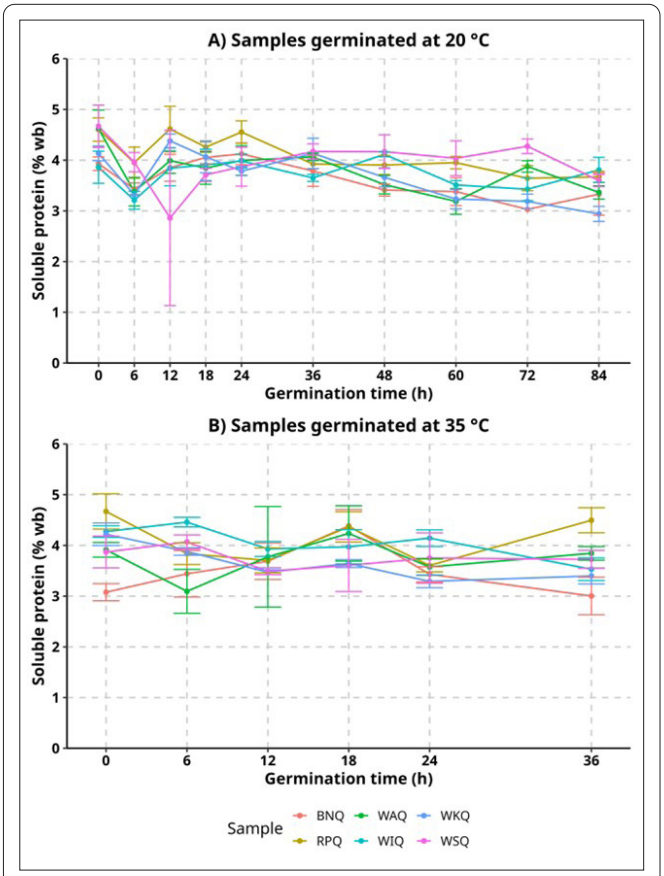


Figure 1: Soluble protein content of different quinoa cultivars over time. All values are expressed as mean ± SE.

During the germination process, only the effects of time ($p = 0.02$) and cultivar ($p \leq 0.01$) were significant regarding the concentration of soluble protein. None of their interactions were significant. The soluble protein content did not vary significantly over time for all cultivars studied at 20 °C, except for WKQ, which varied and slightly decreased over time to 48 h and more markedly after 60 h. The same phenomenon was observed during germination at 35 °C, where the soluble protein content in WKQ decreased significantly from 24 h onward. RPQ had relatively higher initial soluble protein contents (4.64%) among the cultivars analyzed for the two temperatures, a value that slightly increased to 12 h of germination at 20 °C, compared to 35 °C. Chaparro-Rojas et al. [7] pointed out that the total protein content of Colombian quinoa cultivars did not vary significantly after germination for 48 and 72 h. Except for BNQ, which had a slight increase, Valenzuela Antezana et al. [8] did not find a significant variation in protein content after germinating WSQ and RPQ seeds for 48 h at 20 °C. Zhang et al. [33] reported that germinating a Chinese quinoa variety for 48 h at 20 °C optimized selenium enrichment, but that control seeds germinated without selenium yielded the highest soluble protein content. We selected the RPQ cultivar and a germination condition of 12 h at 20 °C for porridge preparation. After spray-drying, the total protein contents of flour from germinated and non-germinated seeds were 9.22 ± 0.74% wet basis (wb) and 7.71 ± 0.18% wb, respectively.

Reducing sugar content

The content of reducing sugars in the germinated seeds at 20 and 35 °C is shown in figure 2. All factors and interactions were significant ($p \leq 0.01$). There was a significant interaction between time and temperature for each cultivar. All cultivars increased their content of reducing sugars with germination time at both temperatures. At 20 °C, RPQ was the cultivar that reached its highest level of reducing sugars earliest (36 h), while WKQ reached it later (84 h). At 35 °C, BNQ was the one to reach its highest level of reducing sugars the fastest, while RPQ and WKQ were the last (36 h). Bhinder et al. [13] reported the content of reducing sugars in samples of white and black quinoa after 24, 48, 72, and 96 h of germination at 24 °C, obtaining values similar to ours and also observing an increase over time. He et al. [28] also determined the content of reducing sugars in varieties of red, black, and white quinoa during germination, also finding an increase over time but only up to 48 h after germination at 22 °C in darkness for 2 days, after which it decreases markedly. The values they observed were higher than those of the present study. An even higher range (29.73 - 42.75 g/100 g db) was previously reported by Jimenez et al. [29] for an Argentine variety of quinoa germinated at 22 - 24 °C for 24 h.

Acidity and pH

The acidity and pH of the germinated seeds at 20 °C of the different quinoa varieties is shown in table 4. There is a significant effect of the time ($p < 0.01$), but its interaction with the cultivar was not significant. The initial acidity for RPQ and BNQ was lower than that observed by Quinto et al. [30] for the same cultivars. Meanwhile, Chacón and Montes [11]

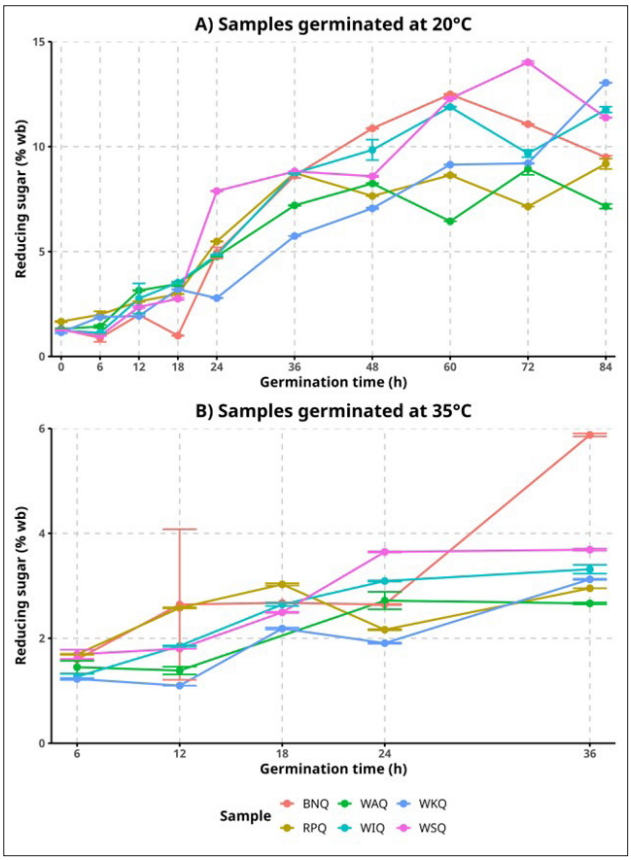


Figure 2: Reducing sugar content of different quinoa cultivars over time. All values are expressed as mean ± SE.

reported lower values for RPQ, BNQ, and WAQ after germination for 24 and 36 h at different temperatures (30 ˚C for RPQ and WSQ, 20 ˚C for BNQ). The acidity increased over time for all cultivars, with WAQ and BNQ having the highest values after 84 h.

Quinto et al. [30] reported lower initial pH values for RPQ and BNQ (6.20 and 6.45, respectively). The values observed by Chacón and Montes [11] were similar to those obtained in the present study for RPQ and BNQ, while the value they obtained for WSQ (6.14 after germination for 24 h at 30 ˚C) was higher than ours. For all analyzed cultivars, the pH trend was inversely proportional to time, except for WSQ, which increased its pH at 36 h.

Characteristics of porridge

The average particle size of the porridge prepared with GQP and NQP was 311 and 263 µm, respectively. Regarding proximate composition, the moisture, protein, fat, ash, fiber, and carbohydrate content of the porridges were 2.70, 13.20, 0.50, 2.82, 24.42, and 53.36% wb, respectively, for NQP; and 2.76, 13.85, 0.22, 2.88, 9.14, and 71.15% wb for GQP. The calculated energy per 100 g of GQP was 360.26 kcal, whereas for NQP it was 325.58 kcal. Similar values were reported for protein content in a porridge formulated with non-germinated quinoa flour [5]. Jimenez et al. [12] also reported similar values for porridges formulated with mixtures of germinated and non-germinated quinoa and amaranth seed flour.

Microbiologically, both porridges presented count below the detection limit of the methods (<10 CFU/g) for APC, molds and yeasts, coliforms, *Staphylococcus aureus*, *B. cereus*, and *Salmonella* spp. (absence). Therefore, both comply with the microbiological requirements of Peruvian regulations [16].

The mean scores from the sensory analysis for odor were 3.50 for GQP and 3.83 for NQP, while for flavor, they were 3.17 and 3.33, respectively. According to Suárez-Estrella et al.

Table 4: Acidity and pH of different quinoa varieties germinated at 20 ˚C over time.

Time (h)	Acidity (% v/w, wb)					
	RPQ	BNQ	WIQ	WAQ	WSQ	WKQ
0	0.00 ± 0.00^{f}	0.01 ± 0.02^{f}	0.06 ± 0.02^{e}	0.18 ± 0.01^{e}	0.00 ± 0.00^{g}	0.05 ± 0.03^{f}
6	0.00 ± 0.00^{f}	0.13 ± 0.02^{e}	0.14 ± 0.01^{e}	0.21 ± 0.03^{de}	0.17 ± 0.00^{f}	0.11 ± 0.02^{ef}
12	0.23 ± 0.02^{e}	0.17 ± 0.00^{e}	0.15 ± 0.00^{e}	0.22 ± 0.00^{de}	0.18 ± 0.02^{f}	0.12 ± 0.00^{e}
18	0.51 ± 0.01^{b}	0.27 ± 0.03^{d}	0.27 ± 0.04^{d}	0.33 ± 0.02^{d}	0.28 ± 0.02^{e}	0.17 ± 0.00^{de}
24	0.32 ± 0.00^{d}	0.33 ± 0.02^{d}	0.36 ± 0.02^{d}	0.38 ± 0.00^{d}	0.29 ± 0.00^{e}	0.22 ± 0.00^{d}
36	0.38 ± 0.02^{c}	0.34 ± 0.00^{d}	0.28 ± 0.02^{d}	0.32 ± 0.04^{de}	0.44 ± 0.00^{d}	0.31 ± 0.02^{c}
48	0.54 ± 0.00^{b}	0.46 ± 0.00^{c}	0.59 ± 0.00^{c}	0.66 ± 0.07^{c}	0.51 ± 0.00^{c}	0.54 ± 0.00^{b}
60	0.54 ± 0.03^{b}	0.59 ± 0.02^{b}	0.64 ± 0.00^{bc}	0.66 ± 0.07^{c}	0.67 ± 0.02^{b}	0.49 ± 0.03^{b}
72	0.56 ± 0.00^{b}	0.57 ± 0.01^{b}	0.69 ± 0.05^{b}	0.84 ± 0.05^{b}	0.70 ± 0.04^{b}	0.51 ± 0.00^{b}
84	0.67 ± 0.02^{a}	1.04 ± 0.04^{a}	0.85 ± 0.03^{a}	1.24 ± 0.05^{a}	0.82 ± 0.02^{a}	0.74 ± 0.00^{a}
	pH					
0	7.03 ± 0.04^{a}	6.89 ± 0.05^{a}	6.78 ± 0.04^{a}	6.60 ± 0.14^{a}	7.10 ± 0.14^{a}	6.90 ± 0.14^{a}
6	6.83 ± 0.04^{b}	6.58 ± 0.11^{b}	6.57 ± 0.07^{ab}	6.40 ± 0.04^{ab}	6.77 ± 0.17^{ab}	6.65 ± 0.07^{ab}
12	6.73 ± 0.04^{b}	6.19 ± 0.01^{c}	6.38 ± 0.01^{bc}	6.21 ± 0.01^{bc}	6.46 ± 0.00^{bc}	6.45 ± 0.01^{bc}
18	6.51 ± 0.08^{c}	6.01 ± 0.04^{cd}	6.18 ± 0.04^{c}	6.03 ± 0.04^{c}	6.01 ± 0.08^{de}	6.28 ± 0.11^{cd}
24	6.08 ± 0.00^{d}	5.86 ± 0.01^{d}	5.90 ± 0.00^{d}	6.01 ± 0.02^{c}	5.71 ± 0.02^{ef}	6.21 ± 0.07^{cd}
36	5.92 ± 0.00^{e}	5.99 ± 0.03^{d}	6.15 ± 0.01^{cd}	5.96 ± 0.00^{c}	6.13 ± 0.00^{cd}	6.04 ± 0.01^{d}
48	5.73 ± 0.01^{f}	5.85 ± 0.01^{d}	5.54 ± 0.01^{e}	5.47 ± 0.01^{de}	5.75 ± 0.01^{def}	5.62 ± 0.01^{e}
60	5.72 ± 0.01^{f}	5.57 ± 0.00^{e}	5.34 ± 0.01^{e}	5.56 ± 0.06^{d}	5.45 ± 0.03^{fg}	5.66 ± 0.01^{e}
72	5.78 ± 0.02^{f}	5.56 ± 0.05^{e}	5.40 ± 0.20^{e}	5.19 ± 0.23^{e}	5.29 ± 0.16^{g}	5.70 ± 0.01^{e}
84	5.43 ± 0.01^{g}	4.69 ± 0.03^{f}	5.35 ± 0.03^{e}	4.39 ± 0.03^{f}	5.07 ± 0.14^{g}	5.09 ± 0.04^{f}

Note: Different superscript letters in the same column indicate significant differences between the means ($p < 0.05$).

[10], germination (48 h at 22 °C) reduced the bitter taste and astringency of quinoa flour by lowering the SP. However, in our study, we did not observe a significant difference in odor and flavor between the porridges. The consistency scores for GQP and NQP were 3.20 and 3.50, respectively. Regarding strange flavor, GQP had a mean score of 2.33, while NQP had a mean score of 1.33. Conversely, Jimenez et al. [12] reported a significant difference in sensory characteristics such as odor, flavor, texture, and firmness between porridges made with germinated and non-germinated quinoa and amaranth seeds, with the non-germinated seeds receiving more favorable ratings. In our study, however, we did not identify a significant difference in consistency or strange flavor between GQP and NQP. Finally, the overall acceptability of both porridges was not significantly different either, with mean scores of 2.96 for GQP and 3.00 for NQP, falling within the mid-range of the scale.

From a formulation standpoint, the GQP offers clear advantages for the development of nutrient-dense, clean-label instant foods. The increase in protein and energy density in GQP supports the creation of high-protein, energy-rich breakfast or meal-replacement porridges. Its slightly larger particle size promotes rapid reconstitution and smooth mouthfeel, while the demonstrated microbiological safety allows for minimal use of preservatives. Sensory scores for odor, flavor, and overall acceptability remained equivalent to the non-germinated product, confirming that these nutritional and functional enhancements can be achieved without compromising consumer appeal. Together, these attributes position GQP as a promising ingredient for next-generation quinoa-based instant porridge formulations.

Conclusion

This study provided a comprehensive comparison of six Peruvian quinoa cultivars germinated at two contrasting temperatures. White cultivars WAQ and WSQ exhibited the most rapid radicle growth at 20 °C, whereas all six cultivars showed reduced growth at 35 °C, highlighting the importance of moderate germination temperatures for optimal seed performance. Germination time was shown to differentially affect soluble protein and reduce sugar profiles: RPQ accumulated reducing sugars most rapidly at 20 °C, BNQ did so at 35 °C, and only WKQ exhibited a significant decline in alkali-soluble protein over time. These findings deepened our understanding of how genotype and germination conditions jointly regulated key biochemical transitions in quinoa.

An instant porridge produced from RPQ flour germinated for 12 h at 20 °C achieved higher protein content and energy density than its non-germinated counterpart, without compromising microbiological safety or sensory acceptability. This demonstrated that a brief, controlled germination step could be readily integrated into industrial processing to yield value-added, nutrient-dense quinoa products.

Future research should assess the *in vitro* and *in vivo* digestibility of proteins and carbohydrates enhanced by germination and determine the bioavailability of associated phytonutrients. Extended storage trials are also warranted to evaluate the shelf-life stability of germinated quinoa flours under commercial packaging conditions. Finally, broadening product applications beyond porridges, such as incorporating germinated quinoa flour into baked goods or extruded snacks, will further demonstrate the versatility of controlled germination as a tool for developing innovative, nutrient-dense quinoa-based foods.

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Conflict of Interest

None.

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