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Effect of Soaking Temperature on the Changes in Composition of Bioactive Compounds in Sprouted Quinoa Seeds (*Chenopodium quinoa* Willd.)

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ABSTRACT

Germination is a simple bioprocess that can improve the functional value of quinoa, but the effect of pre-germination soaking temperature on the variation in bioactive compounds remains unclear. This study evaluated the effects of soaking temperature (25, 30, and 35°C for 4 h) followed by 24 h dark germination on germination percentage, γ-aminobutyric acid (GABA), total saponin content, and DPPH radical-scavenging activity of Cahuil quinoa (*Chenopodium quinoa* Willd.) seeds. Experiments were conducted in three independent replicates. Soaking at 30°C produced the highest germination percentage (33.53 ± 1.40%), significantly exceeding those obtained at 25°C (30.30 ± 2.00%) and 35°C (30.90 ± 1.70%) ($p < 0.05$). In contrast, GABA increased markedly with soaking temperature and reached 2.44 ± 0.11 mg/g at 35°C, compared with 0.93 ± 0.04 and 1.06 ± 0.05 mg/g at 25 and 30°C, respectively. Total saponin content was not significantly affected by soaking temperature and ranged from 29.73 ± 3.05 to 31.78 ± 4.33 mg/g. DPPH radical-scavenging activity was highest after soaking at 35°C (9.76 ± 0.37 µmol TE/g DM), followed by 25°C (8.61 ± 0.14 µmol TE/g DM), and was lowest at 30°C (6.31 ± 0.03 µmol TE/g DM). These results indicate that, among the tested temperatures, 35°C is the most suitable soaking temperature for promoting GABA accumulation and antioxidant activity in quinoa seeds.

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1. Introduction

Quinoa (*Chenopodium quinoa* Willd.) is an Andean pseudocereal increasingly used in nutritional and functional foods because of its balanced composition of protein, starch, dietary fiber, minerals, unsaturated lipids, and diverse phytochemicals [1], [2]. It is naturally gluten-free and can be incorporated into flours, flakes, bakery products, cereal bars, extruded foods, and beverages [2], [3]. Quinoa also contains phenolic acids, flavonoids, betalains, tocopherols, carotenoids, phytosterols, and saponins, which have been associated with antioxidant and other health-related properties [4], [5]. Its bioactive profile, however, varies with genotype, seed color, processing history, and the relative proportions of free, conjugated, and bound phenolics [4], [6]. Changes during digestion further indicate that bioaccessibility should be considered in addition to extractable phytochemical content [7].

Germination is a simple, low-cost, and environmentally friendly bioprocess that can improve the nutritional and functional properties of grains and pseudocereals [8], [9]. Seed hydration activates respiration, enzyme synthesis, reserve mobilization, and extensive metabolic reorganization [10]. These changes can improve nutrient availability and digestibility, reduce some antinutritional factors, and stimulate the release or synthesis of bioactive compounds [8], [11]. In particular, germination may alter phenolic metabolism by releasing bound phenolics, transforming conjugated compounds, and promoting

de novo synthesis through phenylpropanoid-related pathways [12]. Because newly formed metabolites can also be consumed or transformed during sprout development, changes in phenolics and antioxidant capacity are often non-linear and depend strongly on cultivar and processing conditions [12], [13].

Quinoa-specific studies confirm that germination can substantially modify phytochemical and antioxidant properties. Carciochi et al. [14] reported changes in antioxidant compounds following germination and fermentation, while Pilco-Quesada et al. [15] showed that germination combined with kilning affected phenolic and nutritional characteristics. In addition, Bhinder et al. [16] demonstrated that malting influenced phenolic composition, antioxidant properties, mineral content, antinutritional factors, and Maillard reaction products. Germination may also improve mineral utilization through reductions in phytate and increases in phytase activity. Maldonado-Alvarado et al. [17] showed that desaponification, soaking, germination, and refrigerated storage affected phytic acid, phytase activity, and nutritional properties in different quinoa types.

The response to germination is nevertheless highly dependent on seed type and treatment duration. Guardianelli et al. [18] found different optimal germination times for white and red royal quinoa, whereas Ramos-Pacheco et al. [19] reported time-dependent changes in proximate composition, minerals, phenolics, flavonoids, antioxidant capacity, and spectral characteristics in white, red, and black quinoa. Dostalíková et al. [20] similarly observed genotype-dependent changes in bioactive metabolites during germination. These results indicate that a single set of sprouting conditions cannot be assumed to be optimal for all quinoa materials.

Processing conditions must also be considered from a practical safety perspective. The high moisture and moderate temperatures required for sprouting can promote microbial growth, making microbiological control an important limitation for commercial sprouted grains [8], [9]. García-Torres et al. [21] emphasized the need for seed-disinfection strategies that reduce microbial loads without impairing germination, while ultrasound and related emerging treatments have been discussed as approaches that may influence sprout growth, nutritional quality, and microbiological quality [22].

Despite the growing literature, important gaps remain regarding how soaking and germination conditions jointly affect sprout development and bioactive compound accumulation in specific quinoa materials. Many studies emphasize germination time, whereas soaking temperature and related pre-germination conditions may also influence germination percentage and subsequent metabolism. Moreover, genotype-dependent and non-linear responses make it necessary to identify suitable conditions for each seed source rather than extrapolating from other cultivars. Therefore, this study investigated the effect of soaking temperature on the germination of quinoa and evaluated its effects on germination percentage and selected bioactive responses, including γ-aminobutyric acid (GABA), total saponins, and antioxidant activity. The results are intended to support optimization of sprouting as a mild processing strategy for producing quinoa ingredients with improved functional value.

2. Materials and methods

2.1. Materials and chemicals

The quinoa seeds (Cahuil variety) used in this study were provided and authenticated by Assoc. Prof. Dr. Nguyen Van Minh, Dean of the Faculty of Agriculture, Tay Nguyen University.

Analytical-grade methanol, ethanol, phenol, vanillin, sulfuric acid, boric acid, sodium hydroxide, and sodium hypochlorite were purchased from BMS Co., Ltd. (Ho Chi Minh City, Vietnam). γ-Aminobutyric acid (GABA), DPPH (2,2-diphenyl-1-picrylhydrazyl), aescin, and Trolox were provided by Merck Vietnam Ltd. (Ho Chi Minh City, Vietnam).

2.2. Germination process

The seeds were soaked in distilled water at a seed-to-water ratio of 1:10 (w/v) at 25, 30, and 35°C for 4 h. During soaking, the seeds were mixed at 30 min intervals. After 4 h, the soaking water was completely drained. The seeds were then spread evenly on Petri dishes lined with a moist cloth or absorbent paper and covered with another moist layer. The Petri dishes were placed inside a cardboard box under dark conditions. A few small holes were made around the box, and the lid was closed but not

sealed, leaving a gap of approximately 2 mm to maintain limited air and heat exchange with the surrounding environment and to facilitate mist spraying during germination. The seeds were germinated for 24 h at room temperature, and moisture was maintained by spraying the covering material with a fine mist at 6 h intervals. After 24 h of germination, germinated and non-germinated seeds were separated manually and counted. A seed was classified as germinated when visible radicle emergence was observed. Germination percentage was calculated as (number of germinated seeds / total number of seeds) × 100. Only the germinated fraction was used for the biochemical analyses.

2.3. Preparation of extracts for chemical analyses

For the DPPH, total saponin, and GABA assays, a sample of 5 g of germinated quinoa seeds was ground with a ceramic mortar and pestle and then mixed with 100 mL of methanol and transferred into a beaker. Extraction was carried out in an ultrasonic bath for 20 min at room temperature. The mixture was then centrifuged at 5000 rpm for 30 min and filtered through filter paper to obtain the methanolic extract for analysis.

2.4. Determination of antioxidant activity by the DPPH assay

Antioxidant activity was evaluated by the DPPH radical-scavenging assay using Trolox as the reference standard [19]. A DPPH solution was prepared in methanol at approximately 0.15 mM. A Trolox calibration series of 25, 75, 100, 200, and 300 µM was prepared in methanol. For sample analysis, 0.4 mL of the methanolic quinoa extract was mixed with 2.0 mL of DPPH solution. The reaction mixture was incubated in the dark for 30 min, after which the absorbance was measured at 517 nm using a UV-Vis spectrophotometer. Antioxidant activity was determined from the Trolox calibration relationship and expressed as µmol Trolox equivalents per gram of dry matter (µmol TE/g DM).

2.5. Determination of total saponin content

Total saponin content was determined by the vanillin-sulfuric acid colorimetric method using aescin as the reference standard [19]. An 8% (w/v) vanillin solution was prepared in ethanol, and 72% (v/v) sulfuric acid was used as the acidic reagent. Aescin calibration solutions covering the concentration range reported in the experimental protocol were used to construct the standard curve. For each determination, 0.3 mL of diluted sample extract was mixed with 0.3 mL of 8% vanillin solution and 3.0 mL of 72% sulfuric acid. The mixture was incubated at 60°C for 15 min and then cooled in an ice bath for 10 min. Absorbance was measured at 560 nm using a UV-Vis spectrophotometer. Total saponin content was calculated from the aescin calibration curve and expressed as milligrams of aescin equivalents per gram of dry matter (mg AE/g DM).

2.6. Determination of GABA content

GABA content was determined by a colorimetric UV-Vis method [19]. A GABA stock solution was prepared by dissolving 0.1 g of GABA standard in methanol and making the volume up to 100 mL. Calibration solutions in the range of 40–200 µg/mL were prepared from this stock. A 0.2 M borate buffer at pH 9.0 was prepared using boric acid and sodium hydroxide. Phenol solution (6%, w/v) and sodium hypochlorite solution (5.5%, w/v) were used as color-forming reagents. For the assay, 0.2 mL of sample extract was mixed with 0.4 mL of 0.2 M borate buffer (pH 9.0) and 2.0 mL of 6% (w/v) phenol solution. Subsequently, 1.0 mL of 5.5% (w/v) sodium hypochlorite solution was added. The reaction tubes were heated in boiling water for 10 min until a blue color developed, cooled under running water, and the absorbance was measured at 630 nm using a UV-Vis spectrophotometer. GABA concentration was determined from the calibration curve prepared with the GABA standards and calculated based on the dry matter of the material.

2.7. Data analysis

All experiments were conducted in three independent replicates, and data are presented as mean ± standard deviation (SD). Differences among means were analyzed by one-way analysis of variance (ANOVA) followed by the least significant difference (LSD) post hoc test ($p < 0.05$) using Microsoft

Excel 2013 (Microsoft Corp., USA) and Statgraphics Centurion XV (Statpoint Technologies, Inc., USA).

3. Results and discussion

3.1. Effect of soaking temperature on germination percentage

Figure 1 shows non-germinated (A) and germinated (B) quinoa seeds. Soaking temperature significantly affected the germination percentage of quinoa. Seeds soaked at 30°C showed the highest germination percentage, 33.53 ± 1.40%, whereas values of 30.30 ± 2.00% and 30.90 ± 1.70% were obtained at 25 and 35°C, respectively (Figure 2). The 30°C treatment was significantly higher than the other two treatments ($p < 0.05$), while the values at 25 and 35°C did not differ significantly. Relative to 25°C, soaking at 30°C increased germination percentage by approximately 10.7% (relative; 3.23 percentage points), whereas increasing the soaking temperature to 35°C reduced it by about 7.8% (relative; 2.63 percentage points) compared with 30°C.



Figure 1. *Non-germinated (A) and germinated (B) quinoa seeds.*

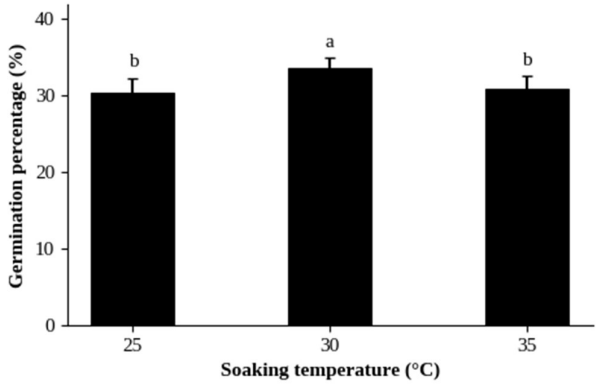


Figure 2. *Effect of soaking temperature on the germination percentage of quinoa seeds.*
Values are mean ± SD (n = 3). Different letters indicate significant differences among treatments ($p < 0.05$).

The response indicates that a moderate soaking temperature favored early germination of Cahuil quinoa. During the initial stages of germination, seed hydration supports membrane reorganization, activation of hydrolytic enzymes, mobilization of reserves, and radicle emergence [10]. Temperature can influence both the rate of water uptake and the metabolic reactions initiated during imbibition. Thus, the most favorable temperature depends on the genotype, duration, and response being optimized. Paucar-Menacho et al. demonstrated that germination temperature and time jointly determine phytochemical accumulation and antioxidant activity in quinoa, with an optimum of 20°C and 42 h for those functional responses [23]. Thakur et al. likewise showed that soaking and germination significantly modify nutritional, antinutritional, and bioactive properties of quinoa [24]. However, water

uptake may also continue during incubation and thereby affect metabolic reactions. As a result, the soaking temperature giving the highest germination percentage is not necessarily the same temperature that maximizes biochemical quality.

3.2. Effect of soaking temperature on GABA content of germinated quinoa

GABA content was strongly affected by soaking temperature (Figure 3). The concentrations were 0.93 ± 0.04, 1.06 ± 0.05, and 2.44 ± 0.11 mg/g for seeds soaked at 25, 30, and 35°C, respectively, and all treatments differed significantly ($p < 0.05$). Soaking at 35°C produced a GABA level approximately 2.62-fold that obtained at 25°C and 2.30-fold that obtained at 30°C. Thus, although 30°C favored the highest germination percentage, the higher soaking temperature of 35°C was considerably more effective for GABA enrichment.

GABA accumulation is a characteristic metabolic response during seed germination. In quinoa, Zhang et al. reported that GABA increased during germination across several varieties and linked this accumulation to regulation of the GABA shunt, particularly glutamate decarboxylase activity and the expression of genes involved in GABA synthesis and catabolism [25]. The strong increase observed at 35°C in the present study may therefore reflect enhanced metabolic activation or a mild temperature-related stress response induced during soaking. This interpretation is consistent with evidence that pre-germination stress can markedly modify GABA metabolism in quinoa. Wu et al. showed that ultrasound treatment before germination increased water absorption, glutamate decarboxylase activity, and GABA accumulation in white quinoa [26]. Together, these findings indicate that soaking temperature is an effective control point for directing GABA enrichment in sprouted quinoa and that maximizing GABA may require conditions different from those that maximize germination percentage.

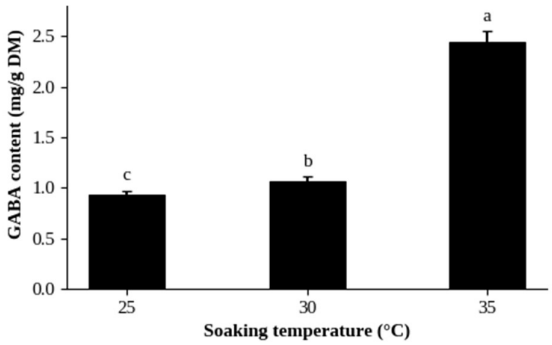


Figure 3. *Effect of soaking temperature on GABA content of germinated quinoa.*
Values are mean ± SD (n = 3). Different letters indicate significant differences among treatments ($p < 0.05$).

3.3. Effect of soaking temperature on total saponin content of germinated quinoa

Total saponin contents of germinated quinoa were 31.78 ± 4.33, 30.94 ± 5.09, and 29.73 ± 3.05 mg/g following soaking at 25, 30, and 35°C, respectively (Figure 4). Although a small downward numerical trend was observed as soaking temperature increased, the three treatments shared the same significance group ($p \geq 0.05$). The difference between the 25 and 35°C treatments was only about 6.5%, indicating that, within the conditions examined, soaking temperature alone did not substantially alter the total saponin content after 24 h of germination.

This result should be interpreted in relation to both soaking and sprouting duration. Quinoa saponins are responsive to wet processing and longer germination, but their changes depend strongly on treatment intensity. Suárez-Estrella et al. reported a progressive reduction in quinoa saponins during sprouting for 12–72 h at 22°C, with the most relevant sensory and compositional changes becoming evident during extended sprouting [27]. In the present study, all samples received the same 4 h soaking period and only 24 h of germination; therefore, the relatively short treatment may have limited the extent of saponin leaching or metabolic transformation, resulting in similar final contents across soaking temperatures. Moreover, the response of saponins is not necessarily parallel to that of other bioactive compounds: pre-

germination ultrasound stress has been reported to increase total saponin content in quinoa while simultaneously enhancing GABA and antioxidant-related components [26]. The absence of a significant temperature effect observed here is therefore plausible and suggests that germination time, washing intensity, or additional pretreatments may be more important variables for controlling saponin levels than soaking temperature within the 25–35°C range.

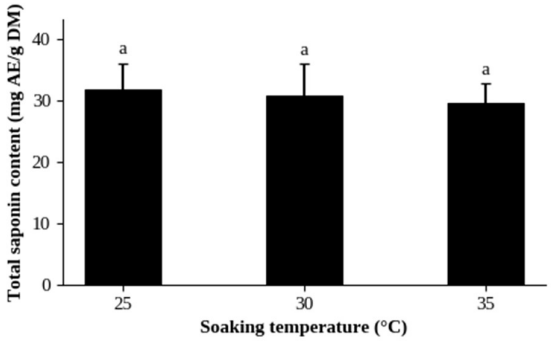


Figure 4. *Effect of soaking temperature on total saponin content of germinated quinoa. Values are mean ± SD (n = 3). Identical letters indicate no significant difference among treatments (p ≥ 0.05).*

3.4. Effect of soaking temperature on antioxidant activity of germinated quinoa

DPPH radical-scavenging activity showed a non-linear response to soaking temperature (Figure 5). The highest activity was obtained at 35°C, with 9.76 ± 0.37 µmol TE/g DM, followed by 25°C with 8.61 ± 0.14 µmol TE/g DM, while the lowest value was recorded at 30°C with 6.31 ± 0.03 µmol TE/g DM. The three treatments differed significantly ($p < 0.05$). Compared with the 25°C treatment, DPPH radical-scavenging activity increased by approximately 13.4% at 35°C, whereas the 35°C treatment was approximately 54.7% higher than the 30°C treatment.

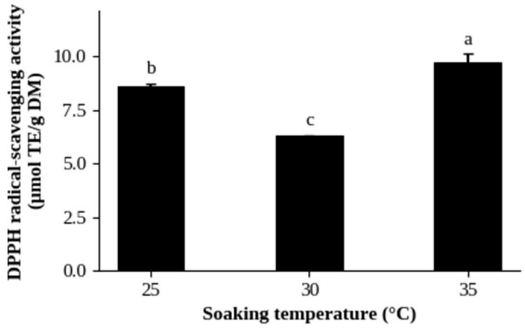


Figure 5. *Effect of soaking temperature on DPPH radical-scavenging activity of germinated quinoa. Values are mean ± SD (n = 3). Different letters indicate significant differences among treatments (p < 0.05).*

Changes in antioxidant activity during germination are governed by multiple processes, including release of bound phenolics, de novo synthesis of phenolic and other antioxidant metabolites, enzymatic transformation, and consumption of antioxidants during active metabolism [12], [14]–[20]. Consequently, antioxidant activity may increase or decrease depending on genotype and germination conditions. Guardianelli et al. found that the antioxidant response to germination differed between white and red quinoa [18], while Paucar-Menacho et al. reported that optimizing germination temperature and time increased total phenolic content and antioxidant activity relative to ungerminated quinoa [23]. The high DPPH activity obtained after soaking at 35°C may therefore be associated with a stronger biochemical response during subsequent germination. Consistent with this concept, Wu et al. observed that a pre-germination stress treatment enhanced DPPH radical-scavenging activity together with several bioactive components in quinoa [26]. Importantly, the present data show that the treatment giving the

highest germination percentage (30°C) produced the lowest DPPH value, whereas 35°C favored GABA and antioxidant activity. This divergence demonstrates that germination percentage and functional composition should be optimized as separate responses when designing sprouted-quinoa processing conditions.

4. Conclusion

Soaking temperature was an important determinant of germination percentage, GABA content, and antioxidant activity, but not of total saponin content, in sprouted Cahuil quinoa under the tested conditions. The highest germination percentage was obtained after soaking at 30°C (33.53 ± 1.40%), whereas soaking at 35°C produced the greatest GABA content (2.44 ± 0.11 mg/g) and DPPH radical-scavenging activity (9.76 ± 0.37 μmol TE/g DM). In contrast, total saponin content was not significantly affected by soaking temperature and remained within 29.73–31.78 mg/g. These results show that a single processing temperature does not simultaneously maximize all desirable responses. A soaking temperature of 30°C is preferable when germination percentage is the primary objective, while 35°C is more suitable when enrichment of GABA and antioxidant activity is prioritized. Therefore, controlling the soaking stage offers a simple approach for directing the functional quality of sprouted quinoa. Further work should evaluate the combined effects of soaking temperature and germination duration, identify the individual antioxidant compounds responsible for the observed activity, and assess post-germination drying and microbiological control to support scale-up for functional food applications.

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Conflict of interest

The authors declare no conflict of interest.

REFERENCES

[1] L. E. Abugoch James, "Quinoa (*Chenopodium quinoa* Willd.): Composition, chemistry, nutritional, and functional properties," *Adv. Food Nutr. Res.*, vol. 58, pp. 1–31, 2009.
[2] V. Angeli *et al.*, "Quinoa (*Chenopodium quinoa* Willd.): An overview of the potentials of the golden grain and socio-economic and environmental aspects of its cultivation and marketization," *Foods*, vol. 9, no. 2, Art. no. 216, 2020.
[3] G. Ren *et al.*, "Nutrient composition, functional activity and industrial applications of quinoa (*Chenopodium quinoa* Willd.)," *Food Chem.*, vol. 410, Art. no. 135290, 2023.
[4] Y. Tang and R. Tsao, "Phytochemicals in quinoa and amaranth grains and their antioxidant, anti-inflammatory, and potential health beneficial effects: A review," *Mol. Nutr. Food Res.*, vol. 61, no. 7, Art. no. 1600767, 2017.
[5] A. Agarwal, Rizwana, A. D. Tripathi, T. Kumar, K. P. Sharma, and S. K. Patel, "Nutritional and functional new perspectives and potential health benefits of quinoa and chia seeds," *Antioxidants*, vol. 12, no. 7, Art. no. 1413, 2023.
[6] G. Qian *et al.*, "Metabolomics analysis reveals the accumulation patterns of flavonoids and phenolic acids in quinoa (*Chenopodium quinoa* Willd.) grains of different colors," *Food Chem. X*, vol. 17, Art. no. 100594, 2023.
[7] G. Balakrishnan and R. G. Schneider, "Quinoa flavonoids and their bioaccessibility during *in vitro* gastrointestinal digestion," *J. Cereal Sci.*, vol. 95, Art. no. 103070, 2020.
[8] P. Benincasa, B. Falcinelli, S. Lutts, F. Stagnari, and A. Galieni, "Sprouted grains: A comprehensive review," *Nutrients*, vol. 11, no. 2, Art. no. 421, 2019.
[9] R. Y. Gan *et al.*, "Bioactive compounds and bioactivities of germinated edible seeds and sprouts: An updated review," *Trends Food Sci. Technol.*, vol. 59, pp. 1–14, 2017.
[10] J. D. Bewley, K. J. Bradford, H. W. M. Hilhorst, and H. Nonogaki, *Seeds: Physiology of Development, Germination and Dormancy*, 3rd ed. New York, NY, USA: Springer, 2013.
[11] K. Nelson, L. Stojanovska, T. Vasiljevic, and M. Mathai, "Germinated grains: A superior whole grain functional food?," *Can. J. Physiol. Pharmacol.*, vol. 91, no. 6, pp. 429–441, 2013.
[12] M. Xu, J. Rao, and B. Chen, "Phenolic compounds in germinated cereal and pulse seeds: Classification, transformation, and metabolic process," *Crit. Rev. Food Sci. Nutr.*, vol. 60, no. 5, pp. 740–759, 2020.
[13] E. Lemmens *et al.*, "Impact of cereal seed sprouting on its nutritional and technological properties: A critical review," *Compr. Rev. Food Sci. Food Saf.*, vol. 18, no. 1, pp. 305–328, 2019.
[14] R. A. Carciochi, L. Galván-D'Alessandro, P. Vandendriessche, and S. Chollet, "Effect of germination and fermentation process on the antioxidant compounds of quinoa seeds," *Plant Foods Hum. Nutr.*, vol. 71, no. 4, pp. 361–367, 2016.
[15] S. Pilco-Quesada, Y. Tian, B. Yang, R. Repo-Carrasco-Valencia, and J.-P. Suomela, "Effects of germination and kilning on the phenolic compounds and nutritional properties of quinoa (*Chenopodium quinoa*) and kiwicha (*Amaranthus caudatus*)," *J. Cereal Sci.*, vol. 94, Art. no. 102996, 2020.

[16] S. Bhinder, S. Kumari, B. Singh, A. Kaur, and N. Singh, "Impact of germination on phenolic composition, antioxidant properties, antinutritional factors, mineral content and Maillard reaction products of malted quinoa flour," *Food Chem.*, vol. 346, Art. no. 128915, 2021.
[17] P. Maldonado-Alvarado, D. J. Pavón-Vargas, J. Abarca-Robles, S. Valencia-Chamorro, and C. M. Haros, "Effect of germination on the nutritional properties, phytic acid content, and phytase activity of quinoa (*Chenopodium quinoa* Willd)," *Foods*, vol. 12, no. 2, Art. no. 389, 2023.
[18] L. M. Guardianelli, M. V. Salinas, C. Brites, and M. C. Puppo, "Germination of white and red quinoa seeds: Improvement of nutritional and functional quality of flours," *Foods*, vol. 11, no. 20, Art. no. 3272, 2022.
[19] B. S. Ramos-Pacheco *et al.*, "Effect of germination on the physicochemical properties, functional groups, content of bioactive compounds, and antioxidant capacity of different varieties of quinoa (*Chenopodium quinoa* Willd.) grown in the high Andean zone of Peru," *Foods*, vol. 13, no. 3, Art. no. 417, 2024.
[20] L. Dostalíková *et al.*, "The impact of germination and thermal treatments on bioactive compounds of quinoa (*Chenopodium quinoa* Willd.) seeds," *Eur. Food Res. Technol.*, vol. 250, no. 6, pp. 1457–1471, 2024.
[21] S. M. García-Torres, J. A. Teixeira, C. R. Encina-Zelada, C. L. M. Silva, and A. M. Gomes, "Effect of different disinfection procedures on the microbiological quality and germination efficacy of sprouted quinoa (*Chenopodium quinoa*) flour," *Foods*, vol. 14, no. 18, Art. no. 3196, 2025.
[22] H. K. Liu *et al.*, "The effects of ultrasound on the growth, nutritional quality and microbiological quality of sprouts," *Trends Food Sci. Technol.*, vol. 111, pp. 292–300, 2021.
[23] L. M. Paucar-Menacho, C. Martínez-Villaluenga, M. Dueñas, J. Frias, and E. Peñas, "Response surface optimisation of germination conditions to improve the accumulation of bioactive compounds and the antioxidant activity in quinoa," *Int. J. Food Sci. Technol.*, vol. 53, no. 2, pp. 516–524, 2018.
[24] P. Thakur *et al.*, "Effect of soaking and germination treatments on nutritional, anti-nutritional, and bioactive properties of amaranth (*Amaranthus hypochondriacus* L.), quinoa (*Chenopodium quinoa* L.), and buckwheat (*Fagopyrum esculentum* L.)," *Curr. Res. Food Sci.*, vol. 4, pp. 917–925, 2021.
[25] D. Zhang *et al.*, "Transcriptome analysis reveals the molecular mechanism of GABA accumulation during quinoa (*Chenopodium quinoa* Willd.) germination," *J. Agric. Food Chem.*, vol. 69, no. 41, pp. 12171–12186, 2021.
[26] M. Wu *et al*., "Enhancement of γ-aminobutyric acid and the characteristics of nutrition and function in white quinoa through ultrasound stress at the pre-germination stage," Foods, vol. 13, no. 1, Art. no. 57, 2024.
[27] D. Suárez-Estrella *et al.*, "Sprouting of quinoa (*Chenopodium quinoa* Willd.): Effect on saponin content and relation to the taste and astringency assessed by electronic tongue," *LWT*, vol. 144, Art. no. 111234, 2021.

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