



Original research

Influence of ultrasonic pretreatment on the quality attributes of sprouted quinoa powder

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ABSTRACT

This study examined the impacts of ultrasonic treatment (40 kHz, 0-150 W, for 5 min) on the moisture content, pH, acidity, color indexes, total phenolic content (TPC), and antioxidant capacity (AC) of sprouted quinoa powder. To produce sprouted quinoa, the quinoa seeds were soaked for 1 h with magnetized water. Then the quinoa seeds were incubated in a magnetic field at 25°C for 72 h for sprouting. The moisture content of the sprouted quinoa powders was in the range of 4.68 % to 6.31 %. The sprouting process and ultrasonic treatment increased the acidity of the quinoa powders, which also reduced the pH of the sprouted quinoa powders. High-intensity ultrasonic treatment (150 W) of quinoa significantly decreased the lightness parameter of the powders ($p < 0.05$). The redness and yellowness indexes of the sprouted quinoa powders were in the range of 3.90 to 3.97, and 12.65 to 13.57, respectively. The findings showed that high-intensity ultrasonic treatment (150 W) significantly increased the TPC of sprouted quinoa powder from 1253.68 µg gallic acid/g to 1350.80 µg gallic acid/g ($p < 0.05$). In addition, with increasing sonication power from 0 to 150 W, the AC of sprouted quinoa powders significantly increased from 88.20 % to 92.97 % ($p < 0.05$). Overall, using high-intensity ultrasonic (40 kHz, 150 W, for 5 min) was selected as the appropriate treatment for sprouted quinoa due to increasing the TPC and AC of quinoa powder.

Keywords: Antioxidant capacity; Color indexes; Magnetized water; Total phenolics; Ultrasound.

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1. Introduction

Quinoa (*Chenopodium quinoa* Willd.) is an Andean grain crop that has gained global attention due to the high nutritional value of its seeds and its favorable eco-physiological characteristics (Alandia et al., 2020; Okon, 2021; Pulvento and Bazile, 2023; Vejdaniwahid and Salehi, 2024).

With the increasing demand for functional foods, sprouted cereals and legumes have gained attention as rich sources of bioactive compounds (Shah et al., 2011; Salehi, 2023a; Goharpour et al., 2024). Germination activates enzymes that improve digestibility and increase vitamins, phenolic compounds, dietary fiber, and antioxidant activity by enhancing the availability of reducing sugars and free amino acids (Ding et al., 2016).

Magnetized water is water passed through a magnetic field. When water is exposed to a magnetic field with positive and negative poles, its molecules become magnetized. This causes the water

molecules to move out of their disordered state and form smaller water clusters, increasing the number of clusters per unit volume and improving the solubility of the magnetized water. Magnetic water has a hexagonal structure, which can have a positive effect on food products (Holysz et al., 2007; Pang and Deng, 2008; Aliverdi et al., 2021; Salehi and Samary, 2024). Irrigation with magnetized water can significantly improve plant growth and development, both quantitatively and qualitatively (Aliverdi et al., 2021).

As a non-thermal method, ultrasound has a wide range of applications in the food industry. This technique uses more frequent sound waves than the human audible area (over 20 kHz). Ultrasound uses support in processes such as extracting phenolic compounds and dietary fiber, inactivation of enzymes such as peroxidase and lipoygenase, and assistance in processes such as freezing, thawing, drying, and inactivating microorganisms and enzymes (Salehi, 2023b; Nabi et al., 2024). Yang et al. (2024) investigated the effect of ultrasound treatment on the structural and functional properties of

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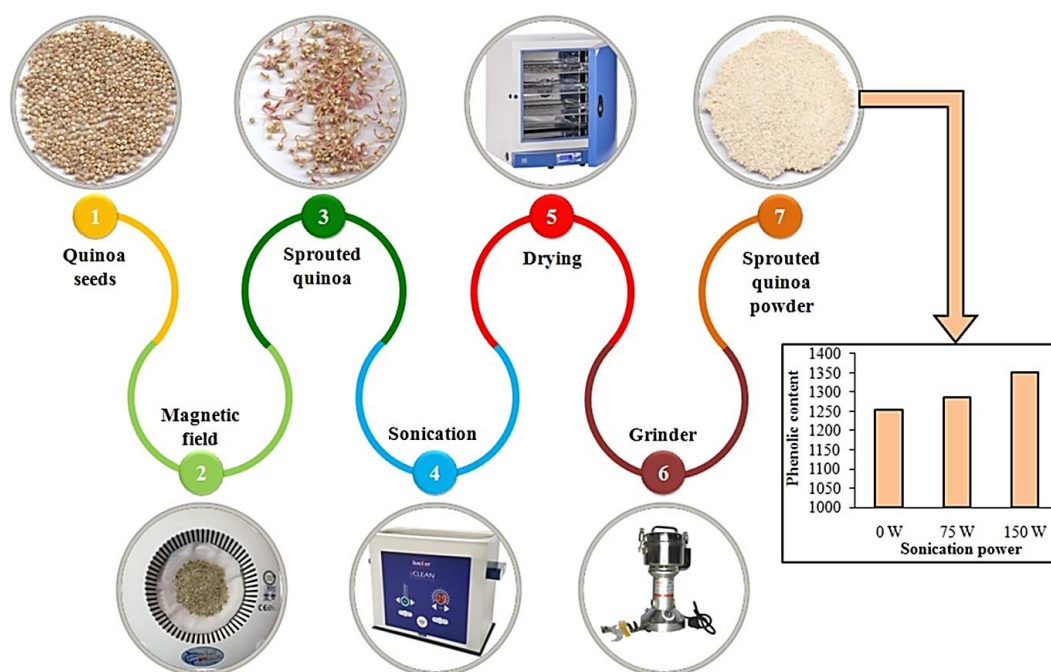


Fig. 1. Steps of sprouting, sonication, and drying of sprouted quinoa to prepare powder.

quinoa protein and reported that the use of ultrasound at optimal intensity creates positive changes in the spatial structure of proteins. These changes occur through mechanical vibration and cavitation phenomena and ultimately affect the functional and digestive properties of proteins.

The objective of this work was to determine the impact of ultrasonic treatment on the moisture content, pH, acidity, color indexes, total phenolic content (TPC), and antioxidant capacity (AC) of sprouted quinoa powder.

2. Materials and Methods

2.1. Quinoa sprouts

We purchased white quinoa seeds harvested from Iran (packaged by OAB Company, Iran). First, the seeds were washed and soaked in magnetized water in a magnetic field for 1 h at 25°C. Then, the seeds were poured into a flat container and covered with a thin towel. During the sprouting stage, the seeds were placed entirely inside the magnetic field along with the container and towel (Fig. 1). The seeds were moistened with a water sprayer bottle every 6 hours. In total, the seeds were kept at a temperature of about 25°C for 72 hours until they sprouted (Vejdanivahid and Salehi, 2024).

A magnetic-alkaline ionized water production device (bipolar model with timer, Meghnatis Sazan Hayat Co., Iran) was used to magnetize the water and prepare the magnetized water. The intensity of the magnetic field generated by the device was measured using a Gauss meter (Model TES-3196, Taiwan). The magnetic field intensity generated by the device was 2.8 Gauss and the magnetic field intensity of the magnetized water inside the device was 1.4 Gauss.

2.2. Ultrasonic treatment

Ultrasonic treatment was applied to the sprouted quinoa seeds using an ultrasonic water bath (Backer, vCLEAN1-L6, Iran), a water capacity of 6 L, 40 kHz, and three power levels (0, 75, and 150 W). The sprouted quinoa seeds were placed directly in the water bath at 25°C for 5 min (Vejdanivahid and Salehi, 2025).

2.3. Hot-Air drying

The ultrasonic-pretreated sprouted quinoa seeds were dried at 70°C using a convection oven (Shimaz, Iran), and the weight of the samples was measured every 5 min using a digital balance (GM-300p, Lutron, Taiwan) with a precision of 0.01 g until a constant weight was reached.

2.4. Powdering the dried sprouts

Dried quinoa sprouts were ground using an industrial grinder (Best, China). The prepared powder was packed into polyethylene bags to prevent moisture absorption during storage. The bags were then stored in a refrigerator at 6°C until the experiment.

2.5. Moisture content

A moisture analyzer (DBS 60-3, Kern, Germany) was used to measure the moisture content of sprouted quinoa powder.

2.6. pH of powders

According to Iranian National Standard No. 37 (2018), to measure the pH of the sprouted quinoa powder, ten g of the powder

was mixed thoroughly with 100 mL of distilled water and left for 20 min. After calibrating the pH meter electrode (Metrohm, 827pH lab, Switzerland) with buffer solutions 4 and 7, the pH of the aqueous phase was estimated with the pH meter.

2.7. Acidity of powders

Acidity of sprouted quinoa powder was determined according to [Iranian National Standard No. 103 \(2018\)](#). Briefly, 10 g of powder was extracted with 50 mL of 67% ethanol (Kimia Alcohol Zanjan Co., Iran), filtered after stirring, and 25 mL of the filtrate was titrated with 0.1 N NaOH using 3% phenolphthalein as an indicator. Acidity was calculated according to the method described by [Samary et al. \(2025\)](#).

2.8. Color parameters of powders

Image processing methods were used to measure the color parameters of sprouted quinoa powder. The surface images of powders were captured with a scanner (HP Scanjet-300). The color space of the photos was converted from RGB to L* (lightness), a* (green/red), and b* (blue/yellow) using ImageJ software (V.1.42e, USA) and the corresponding plugin ([Samary et al., 2025](#)).

2.9. Total phenolic content (TPC)

The TPC of sprouted quinoa powder was measured using the method explained by [Salehi and Vejdaniavahid \(2025\)](#). Sample extract was prepared by mixing 2 g of sample with 20 mL of 80% methanol and stirring for 30 min, followed by centrifugation (Universal 320R, Hettich, Germany) at 4000 rpm for 5 min. Absorbance was measured at 725 nm using a spectrophotometer (XD-7500, Lovibond, Germany). The TPC of sprouted quinoa powder was expressed as microgram gallic acid equivalent per g ($\mu\text{g GAE/g}$).

2.10. Antioxidant capacity (AC)

To estimate the AC of the sprouted quinoa powder, in the first step, a 2,2-diphenyl-1-picrylhydrazyl solution (DPPH, Sigma-Aldrich, USA) was prepared at a concentration of 0.1 mM. Subsequently, the AC of sprouted quinoa powder was calculated according to the procedure of [Salehi et al. \(2023\)](#). To prepare sprouted quinoa powder extract, 2 g of powder was added to 20 mL of 80% methanol and mixed for 30 min with a magnetic stirrer (Shimaz, Iran). After transferring the mixture to a Falcon tube, the Falcon tube was centrifuged for 5 min at 4000 rpm in a centrifuge. After the separation step, the supernatant of the prepared mixture was considered as the extract. To measure the free radical scavenging activity of sprouted quinoa powder, 2 mL of the extract was placed in a test tube along with 2 mL of DPPH solution. The mixture was incubated at 25°C for 30 min and then placed in a dark environment. The absorbance of the samples was read at 517 nm using a spectrophotometer (XD-7500, Lovibond, Germany).

2.11. Statistical analysis

The findings of this work were analyzed using SPSS software (version 21). The tests were performed in triplicate, and Duncan's

multiple range test was used at a 95% confidence level to compare the mean of the observed responses. Excel 2013 was used to draw the graphs.

3. Results and Discussion

3.1. Moisture content

Fig. 2 shows the impact of ultrasonic treatment on the moisture content of the powder obtained from quinoa sprouts. The moisture content of the sprouted quinoa powders was in the range of 4.68 ± 0.08 % to 6.31 ± 0.01 %. High-intensity ultrasonic treatment (150 W) of quinoa significantly decreased the moisture content of the powder ($p < 0.05$). [Amin Ekhlas et al. \(2024\)](#) reported that ultrasound treatment for up to 5 min reduces the microbial population, accelerates the rate of moisture removal from germinated wheat, and increases its effective moisture diffusivity coefficients.

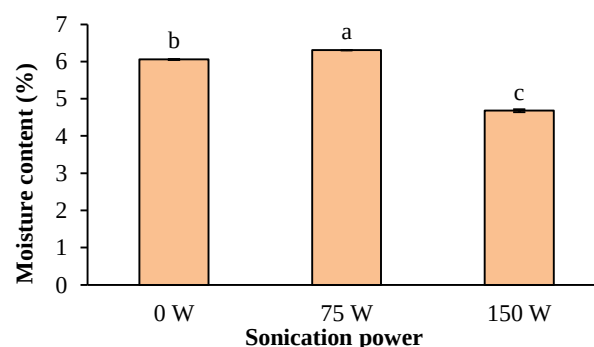


Fig. 2. Influence of ultrasonic treatment on the moisture content of sprouted quinoa powder. Different letters above the columns indicate significant differences ($p < 0.05$).

3.2. pH and acidity of powders

Fig. 3 shows the impact of ultrasonic treatment on the pH of the powder prepared from quinoa sprouts. The highest pH value was found for the untreated sprouted quinoa seeds powder, which showed a significant difference from the other powders ($p < 0.05$). The findings showed that high-intensity ultrasonic treatment (150 W) significantly decreased the pH of sprouted quinoa powder from 5.81 ± 0.01 to 5.66 ± 0.01 ($p < 0.05$).

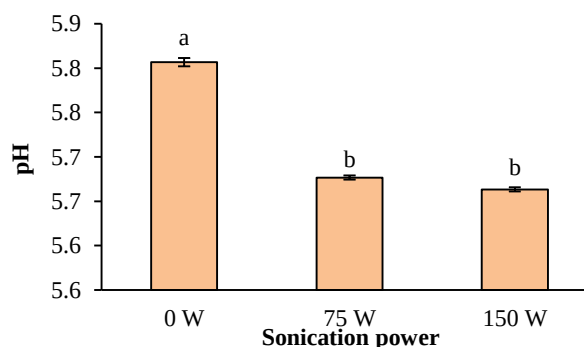


Fig. 3. Influence of ultrasonic treatment on the pH of sprouted quinoa powder. Different letters above the columns indicate significant differences ($p < 0.05$).

In this work, the acidity of the quinoa seed powder used was 0.67%. During sprouting, the acid content of the quinoa increases due to increased enzymatic and microbial activity (Fig. 4). The intensity of ultrasound power did not have a significant effect on the change in the acidity of the powders. The acidity of the sprouted quinoa powders was in the range of 1.60 ± 0.04 % to 1.67 ± 0.01 %.

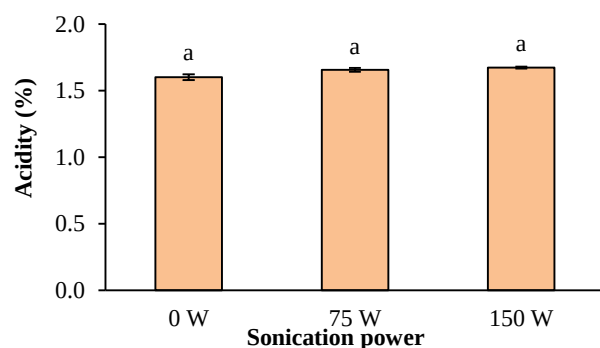


Fig. 4. Influence of ultrasonic treatment on the acidity of sprouted quinoa powder. Same letters above the columns indicate no significant differences ($p > 0.05$).

3.3. Color parameters of powders

When analyzing color indexes, the lightness index or L^* ranges from 0 to 100. The closer this number is to 100, the lighter the sample is. The redness index or a^* ranges from -120 to +120, and a negative value of this index indicates that the sample is green, while a positive value indicates that the surface color is closer to red. The yellowness index or b^* has a range between -120 and +120, and a negative value means that the surface color is closer to blue, while a positive value means that the surface color is closer to yellow (Vejdanivahid and Salehi, 2025). In this study, the L^* , a^* , and b^* values of the quinoa seed powder used in this study were 89.21, 2.03, and 12.41, respectively.

The effect of ultrasonic treatment on the color indexes (lightness, redness, and yellowness) of sprouted quinoa powder are shown in Fig. 5. The results showed that as quinoa seeds sprouted, the lightness parameter of the powders reduced. High-intensity ultrasonic treatment (150 W) of quinoa significantly decreased the lightness parameter of the powders from 82.77 ± 0.24 to 81.20 ± 0.03 ($p < 0.05$). The highest lightness value was found for the low-intensity ultrasonic pretreated sample (75 W), which showed a significant difference from the high-intensity pretreated sample ($p < 0.05$).

Due to increased enzymatic activity and non-enzymatic browning, sprouting of quinoa seeds significantly increased the redness index of the powders. Also, the sprouting rate of quinoa treated with magnetized water was higher than the sample with untreated water, so the redness index of these samples was higher than that of sprouted quinoa with untreated water. According to a report by Ozturk et al. (2014), powder becomes darker than wheat seed powder upon germination, the lightness decreases and the yellowness and redness increase upon sprouting. The intensity of ultrasound power did not have a significant effect on the change in the redness index of the powders. The lowest redness index value was found for the low-intensity ultrasonic pretreated sample. The redness and yellowness indexes of the sprouted quinoa powders were in the range of 3.90 ± 0.02 to 3.97 ± 0.02 , and 12.65 ± 0.13 to 13.57 ± 0.12 , respectively. The highest yellowness index value was

found for the low-intensity ultrasonic pretreated sample, which showed a significant difference from the high-intensity ultrasonic pretreated sample ($p < 0.05$).

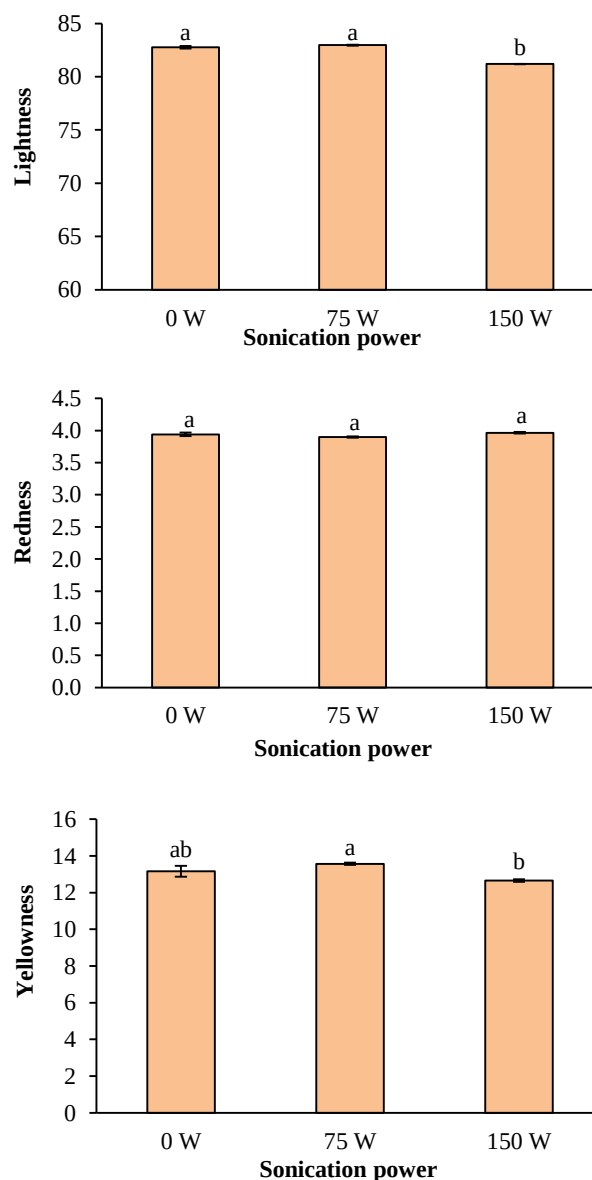


Fig. 5. Influence of ultrasonic treatment on the color indexes (lightness, redness, and yellowness) of sprouted quinoa powder. Different letters above the columns indicate significant differences ($p < 0.05$).

3.4. Total phenolic content (TPC)

The TPC of the quinoa seeds powder used in this study was $758.80 \mu\text{g gallic acid/g}$. During sprouting, the TPC of the quinoa sprouts increases due to increased enzymatic activity. In addition, treatments with ultrasound increase the extracting phenolic compounds from cells, leading to an increase in the TPC in the sprouts and a higher TPC in the powder. In line with the findings of the present work, Gan et al. (2017) reported that the phenolic

compounds in edible seeds increased significantly during sprouting. Fig. 6a shows the impact of ultrasonic treatment on the TPC of quinoa powders. The findings showed that high-intensity ultrasonic treatment (150 W) significantly increased the TPC of sprouted quinoa powder from $1253.68 \pm 41.54 \mu\text{g gallic acid/g}$ to $1350.80 \pm 9.06 \mu\text{g gallic acid/g}$ ($p < 0.05$).

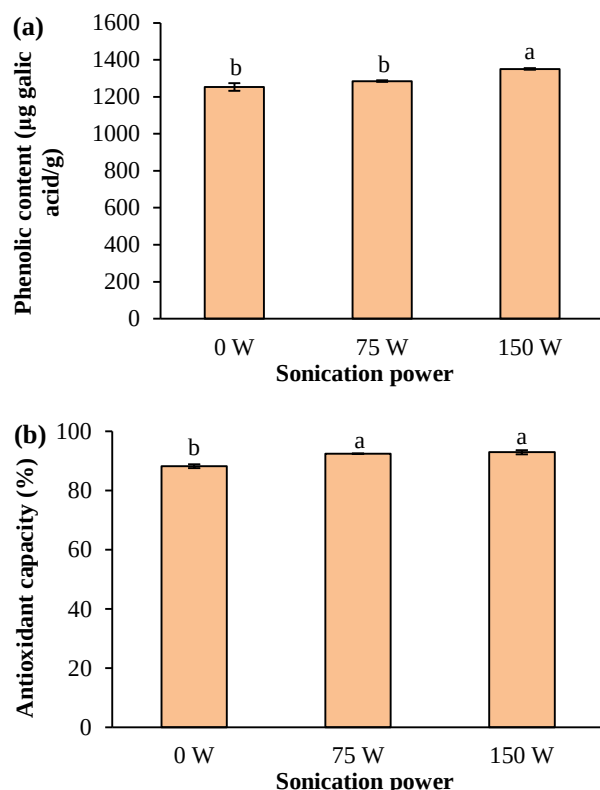


Fig. 6. Influence of ultrasonic treatment on the total phenolic content (a) and antioxidant capacity (b) of sprouted quinoa powder. Different letters above the columns indicate significant differences ($p < 0.05$).

3.5. Antioxidant capacity (AC)

AC is one of the bioactive substances that have been studied in germinated grains and edible seeds, and germination has been shown to increase the AC of many edible seeds. Gan et al. (2017) and Sharma et al. (2018) results also show that the sprouting process increases the AC of extracts from sprouted seeds. Some researchers have reported that the vitamin content, phenolic compounds, and antioxidant capacity of raw quinoa seeds increased significantly 72 h after sprouting (Al-Qabba et al., 2020; Ng and Wang, 2021). The AC of the quinoa powder used in this study was 83.18. During sprouting, the AC of the quinoa sprouts increases due to increased TPC. In addition, treatments with ultrasound increase the extracting phenolic compounds from cells, leading to an increase in the AC in the sprouts and a higher AC in the powder. Fig. 6b shows the effect of ultrasonic treatment on the AC of quinoa powders. This figure shows that the lowest AC was associated with untreated powder. The findings showed that high-intensity ultrasonic treatment significantly increased the AC of sprouted quinoa powder from $88.20 \pm 1.27 \%$ to $92.97 \pm 1.42 \%$ ($p < 0.05$). Overall, using high-

intensity ultrasonic (40 kHz, 150 W, for 5 min) was selected as the best treatment for sprouted quinoa due to increasing the TPC and AC of quinoa powder.

4. Conclusion

Sprouted quinoa is a gluten-free product (proper for people with celiac disease) and contains fiber, and as well as various vitamins, phenolic compounds, antioxidants, and nutrients, and its powder can be used to improve the quality of various foods. Sprouting of quinoa seeds increased acidity and decreased pH of powders. Also, during sprouting, the AC of the quinoa sprouts increases due to increased TPC. High-intensity ultrasonic treatment (150 W) of quinoa significantly decreased the lightness parameter of the powders ($p < 0.05$). The intensity of ultrasound power did not have a significant effect on the change in the redness index of the powders. In summary, the findings of this study showed that high-intensity ultrasonic treatment significantly decreased the moisture content, pH, lightness, of sprouted quinoa powder ($p < 0.05$). Also, the high-intensity ultrasonic treatment significantly increased the TPC and AC of sprouted quinoa powder ($p < 0.05$). Generally, ultrasound treating quinoa sprouts improves the quality of the sprouted quinoa and the powder produced, which can improve the nutritional value of food products containing sprouted quinoa powder. As future research, it is recommended to investigate the effect of ultrasound treatment on the quality of sprouts of other edible seeds.

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Conflict of interest

The authors declare that there is no conflict of interest.

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