Journal of Neonatal Surgery
ISSN(Online): 2226-0439
Vol. 14, Issue 27s (2025)
https://www.jneonatalsurg.com

OPEN ACCESS

The Effect of Thermal Treatments on the Anti-Nutritional Factors of Quinoa Flour for Use in Children's Food

Randa Radwan Abd Al-Jabbar[1], Maryam Malallah Ghazal[1]

[1]Department of Food Sciences, Collage of Agricultural Engineering Sciences, University of Baghdad, Iraq
Email ID: randa.abd2202m@coagri.uobaghdad.edu.iq, Email ID: mar967am@coeduw.uobaghdad.edu.iq

Cite this paper as: Randa Radwan Abd Al-Jabbar, Maryam Malallah Ghazal, (2025) The Effect of Thermal Treatments on the Anti-Nutritional Factors of Quinoa Flour for Use in Children's Food. *Journal of Neonatal Surgery*, 14 (27s), 780-790.

ABSTRACT

This study aims to evaluate the effect of heat treatments (boiling and roasting) on the anti-nutritional components (phytates and tannins) in quinoa flour intended for infant food. Quinoa samples were divided into three groups: untreated, a group treated with boiling (100°C for 20 minutes), and a group treated with roasting (150-160°C for 15 minutes). Phytate and tannin concentrations were evaluated using spectrophotometric techniques, and the results were analyzed using analysis of variance (ANOVA) and Tukey's multiple comparison test. The results indicated significant differences between the groups ($p < 0.05$), meaning a decrease in phytate and tannin concentrations after heat treatments. Phytate concentration decreased from 5240 mg/kg in untreated samples to 4835 mg/kg after boiling, a percentage of (7.7%), and to 4325 mg/kg after roasting, a percentage of (17.5%). Tannin concentrations decreased from 794.8 mg/kg to 720.8 mg/kg after boiling, a percentage of (9.3%), and to 519.6 mg/kg after roasting, a percentage of (34.7%). Roasting proved more effective than boiling in reducing these molecules, indicating that dry heat breaks stable chemical bonds more efficiently. The study finds that heat treatments, especially roasting, improve the nutritional quality of quinoa flour by reducing anti-nutritional components, which may enhance mineral absorption and sensory properties in infant food. Adopting roasting as an optimal method for treating quinoa before incorporating it into infant food is recommended, with future research suggested to explore the balance between reducing anti-nutrients and preserving heat-sensitive nutrients.

Keywords: *Quinoa flour, Anti-nutritional factors, Thermal processing, Children's nutrition, Phytate reduction*

1. INTRODUCTION

Quinoa (*Chenopodium quinoa* Willd.), a pseudocereal indigenous to the Andean region of South America, has gained recognition as a promising functional food owing to its remarkable nutritional attributes. Distinct from most cereal grains, quinoa possesses a complete protein profile that includes all nine essential amino acids, rendering it particularly beneficial in dietary contexts aimed at alleviating malnutrition. Moreover, it serves as an abundant source of dietary fiber, vitamins—especially those of the B-complex group and vitamin E—as well as vital minerals such as magnesium, potassium, iron, and zinc [1]. Its inherently gluten-free characteristic further accentuates its appropriateness for individuals with celiac disease or gluten sensitivities, leading to its increasing incorporation in the production of health-oriented and specialized food items [2]. In light of the specific nutritional requirements for children during their developmental stages, quinoa presents a viable alternative to conventional grains in formulations intended for infants and young children. Nevertheless, a primary obstacle restraining its utilization is the presence of anti-nutritional factors—naturally occurring substances that hinder nutrient absorption and bioavailability. The most prominent constituents in quinoa are phytates (phytic acid) and tannins. Phytates are acknowledged for their capacity to bind vital minerals such as calcium, iron, and zinc, therefore reducing their bioavailability. Conversely, tannins can create insoluble compounds with proteins and enzymes, so further impairing digestibility and nutritional absorption. These consequences are especially pertinent when considering the dietary requirements of children, who are more vulnerable to deficits [3]. Thermal processing techniques, including boiling (wet heat treatment) and roasting (dry heat treatment), are recognized as efficient procedures for reducing anti-nutritional elements in grains and legumes. Boiling may enhance the extraction of water-soluble chemicals and the denaturation of certain anti-nutritional elements, but roasting might induce thermal degradation and inactivation. The use of these procedures to quinoa might substantially improve its nutritional content, rendering it a more suitable ingredient in food items intended for children [3]. Despite the growing interest in quinoa, there is a scarcity of evidence about the particular impacts of different thermal treatments on the concentrations of phytates and tannins in quinoa flour. The aim of this study is to assess and compare the

impacts of boiling and roasting on the levels of these anti-nutritional chemicals. The results are expected to provide significant insights into the optimization of quinoa processing procedures, consequently enhancing its functional application in the creation of healthy and safe food items for children. Despite the nutritional benefits of quinoa, the presence of anti-nutritional factors such as phytates and tannins hinders its full integration into children's diets. It is essential to investigate effective processing methods designed to reduce these chemicals while maintaining the overall nutritional quality of the food..

2. LITERATURE REVIEW

Quinoa seeds possess several bioactive constituents and are occasionally referred to be a superfood. Quinoa, a pseudocereal, is a gluten-free seed crop appropriate for individuals with gluten allergy.. The seeds have good amino acid nutritional quality and an appropriate protein to starch ratio. Quinoa seed has been shown to contain protein, lipid, carbohydrates, organic acids, and other nutrients. Compared with common cereals, quinoa is richer in protein, an appropriate range of essential amino acids, and unsaturated fatty acid content. However, some anti-nutritional factors exist in quinoa. Some components can chelate with different mineral ions and form inert compounds. Therefore, compounds rich in anti-nutritional factors may occupy the active sites, resulting in decreased enzyme activity and digestibility [4].

At present, the bioactivity and bioavailability of bioactive compounds contained in quinoa flour and the effect of different treatments on the content and bioactivity of bioactive compounds have been widely studied. Quinoa flour can effectively alleviate the early symptoms of diabetes, and the anti-diabetic potential the development of diabetes prevention methods in food and nutrition. However, there is little research on the effect of thermal treatments on the content and anti-nutritional properties of anti-nutritional factors in quinoa flour [5].

Nutritional Profile of Quinoa

Quinoa seeds are rich in proteins, amino acids, vitamins (B6, folate, riboflavin, niacin), and a variety of bioactive compounds such as phenolic compounds, phytosterols, and squalene [6]. Nutritionally, quinoa is a highly exceptional food. It is one of the richest plant sources in protein, and quinoa flour or seeds can serve as a source of protein in foods, as a protein supplement, or even as a food in which one can incorporate other food components, such as protein ingredients rich in essential amino acids with lower protein digestibility and/or lower food quality. In addition to high protein content, quinoa contains a well-balanced protein digestibility-corrected amino acid score (PDCAAS) of 0.87 compared to dairy casein (1.0). By PCR analysis, quinoa grains contain no detectable amounts of gliadin or glutenin genes. Thus, these novels gluten-free products should be free of gluten contamination. Moreover, according to comparative analysis of the chemical compositions, quinoa has a much higher fat (5-10%) and a comparable higher ash (1.3-2.9%) and carbohydrate composition (58-76%) than rice, corn, and wheat. Compared with the grain of the other common cereal species, quinoa contains a much higher energy (340-408 kcal) with energy density (1.592 kg/L) and mineral (Ca, Fe, K, Mg, Na, Zn, P) contents; with a comparable amount of starch (50-70%) and dietary fiber (7-25%); and with less or absent levels of glucose, high fructose corn syrup, and starch. Quinoa is a naturally gluten-free substitute for wheat flour, especially for gluten intolerant consumers [7].

Phytates

Phytic acid, commonly known as phytate, is a naturally occurring substance found in various plant materials, especially concentrated in the outer layers of grains, such as bran and germ. It is chemically identified as inositol hexakisphosphate (IP6) and is notable for its capacity to chelate or bind positively charged mineral ions. This includes essential minerals such as Fe^{2+} (iron), Zn^{2+} (zinc), Ca^{2+} (calcium), and Mg^{2+} (magnesium). The chelation process renders these essential minerals less accessible for absorption in the human digestive system, hence complicating the body's capacity to absorb them. Nutritional Effects: Phytic acid markedly impedes the absorption of vital minerals such as iron, zinc, and calcium. This restriction may result in significant health complications, such as iron-deficiency anemia, which is especially common among children in economically disadvantaged regions. Furthermore, the detrimental effects of phytic acid extend to calcium absorption, adversely affecting bone density and general oral health. The adverse consequences of phytate consumption are particularly evident in mostly plant-based diets that lack enough dietary diversification, resulting in an elevated risk of mineral shortages. In the realm of child nutrition, children are more vulnerable to the adverse impacts of phytates owing to their accelerated growth and increased nutritional demands during developmental phases. The possible ramifications of these detrimental impacts encompass stunted growth in height and weight, a compromised immune system resulting in heightened susceptibility to infections, and delays in cognitive and neurological maturation. Awareness and effective control of phytic acid consumption are crucial for ensuring that children acquire the needed minerals for good growth and health [8].

Tannins

Tannins are polyphenolic compounds derived from various plants and are present in seeds, husks, leaves, and bark. These compounds possess the capability to bind with proteins, digestive enzymes, and essential minerals in food, leading to a significant decrease in nutrient digestibility and overall nutrient availability in the body. Tannins can be categorized into two primary types: hydrolyzable tannins and condensed tannins, with the latter being more prevalent in grains and legumes [9]. From a nutritional perspective, tannins form insoluble complexes with proteins, which obstructs protein digestibility and

reduces the nutritional value of the consumed food. They also disrupt the absorption of iron, particularly non-heme iron from plant sources, which is crucial for preventing iron deficiency. Additionally, tannins are known to impart astringent or bitter flavors to foods, which may impact palatability, especially among children who may be more sensitive to variations in taste [10]. For children, the consumption of foods rich in tannins could notably hinder muscle and tissue development due to diminished protein utilization [11]. Furthermore, these compounds may lead to iron deficiency, potentially resulting in serious consequences such as learning difficulties and attention-related issues, which can adversely affect cognitive development. The negative taste characteristics associated with tannins may also influence food acceptance in this demographic, causing reluctance to consume important foods and potentially exacerbating issues related to nutritional intake and health outcomes in developing children [12].

Importance of Children's Nutrition

The term “children’s food” literally means anything edible for children of certain targeted age groups. However, it is important to clarify that children, unlike adults, cannot consume any food meant for them without certain adjustments like grinding, roasting, boiling, or even fermentation. Such adaptations make it desirable, assimilable, and then usable for life functions. This means that nutrient bioavailability as defined for adults, is meaningless when it comes to children. There are particular adaptations needed to guard and deliver nutrients to the bodily pools which are still unacquired in quantity. Cooking and processing techniques on combined food groups favor bioavailability while amelioration is always food specific. Good practices for adults often become poor practices for children, for example, yogurt or cooked legumes and grains [13].

Processed foods for children also referred to as “baby foods” are there in the routine market. They promise for rightful, good, and well-balanced nutrition. These foods are not locally developed for the race in its own raw material or biodiversity. The accessibility of diverse society-specific materials, food processing traditions is not being considered for food design and health. To enable optimal nutrition for young children starting their meals with good practices and adaptive technology in which right nutrients from non-conventional foodstuffs is a necessity. This is never easy as children do have peculiar feed, food behavior, and therefore appropriate processing technique. Nevertheless, processing and preparation methods practiced across continents and centuries can always be tried and re-investigated at local levels for proper nutritive and bioavailability [14]**.**

As a sulfo-grouped non-conventional edible species of Chenopodiaceae, quinoa (Chenopodium quinoa) offers an exemption from these kinds of stories. Very limited processing practices or food adjustments are available for extractions or bioavailability studies. This however adds more interest as quinoa on its own possesses remarkable compositional, nutritional, biochemical, and health properties. Nutrition, health, and sustainability from its early domestication made quinoa popular among scientists and growers challenging the sanitary status of the current food greatest. Quinoa protein is top quality and comparable to that of animal proteins often recommended at par with soyabean which is followed by many attempts for bioavailability assessments [15].

Thermal Treatments Overview

Thermal processing techniques used for food products play a vital role in ensuring safety, stability, flavor, and nutritional quality. Common methods such as cooking, baking, roasting, extrusion, and popping are frequently utilized to process cereals, pulses, nuts, and tubers in various regions of Asia and Africa. Specific processes, including nixtamalization, soaking, boiling, and grilling, are essential for the preparation of staple foods such as maize, millet, and sorghum, especially in Mozambique and Zimbabwe. In Botswana and Malawi, traditional methods like parboiling of sorghum and millet, followed by roasting or toasting, result in the conversion of these grains into a coarse porridge or semi-solid dishes that are favored by the local population. In Zambia, decorticated cereals undergo boiling and fermentation, which alters their color and flavor, enhancing their appeal to consumers. These traditional techniques significantly affect the nutritional composition of the food, leading to a notable reduction in anti-nutritional substances found in raw ingredients. Compounds like phytate, tannins, saponins, phenols, trypsin inhibitors, and lectins can interfere with nutrient absorption and may pose health risks if not properly addressed. Additionally, some anti-nutritional factors may have both positive and negative impacts, highlighting the necessity of thorough processing considerations for both food producers and consumers [16].

Types of Thermal Treatments

Thermal treatments are absolutely essential processes within the broader field of food processing, primarily focusing on improving food safety, enhancing digestibility, modifying sensory characteristics, and effectively decreasing anti-nutritional compounds such as phytates, tannins, and trypsin inhibitors. The careful selection of a specific thermal method is notably influenced by several factors, including the type of food being processed, specific nutritional aims, and varying processing conditions [10] [17]. The following is an in-depth and comprehensive analysis of the primary thermal treatments that are commonly utilized in the processing of cereal grains and pseudocereals, with a particular emphasis on the unique attributes of quinoa:

1. Boiling (Moist Heat Treatment) Definition: Boiling is the process of cooking food in water that is heated to a temperature of 100°C, which facilitates the extraction of water-soluble compounds such as tannins and phytates into the cooking water

itself. Nutritional Impact: This method effectively reduces anti-nutritional components such as phytates and tannins, enhances protein digestibility significantly, and increases mineral bioavailability, while still maintaining nutritional value if the cooking water happens to be retained and consumed. [18] Application: It is commonly used for the preparation of various porridges or smooth purees that are particularly suitable for infants and children, as it represents a gentle cooking method that is most appropriate for sensitive populations and ensures food safety [19].

2. Roasting (Dry Heat Treatment) Definition: Roasting involves the application of direct dry heat to food, typically at temperatures ranging from 120°C to 180°C, and this is usually done in ovens or on hot plates designed for this purpose. Nutritional Impact: This innovative technique significantly decreases tannin levels present in foods, enhances the flavor and texture remarkably, thus making these foods more appealing for children; however, it may also lead to some degree of nutrient loss, particularly of those heat-sensitive nutrients which are vital for health. Application: It is frequently utilized to create a variety of crunchy snack products derived from quinoa, thereby enhancing sensory appeal and extending shelf life effectively, making the snacks not only enjoyable but also suitable for a wide array of consumers [20].

3. MATERIALS AND METHODS

The white quinoa seeds were purchased from local markets under the brand (equia), cleaned of impurities, then ground and stored until laboratory tests could be conducted on them.

Study Design

A laboratory pilot study was conducted to evaluate the effect of two heat treatments (blanching and roasting) on the levels of two anti-nutritional compounds in quinoa flour, namely phytic acid and tannins, with the aim of improving the nutritional value of the flour when used in food products intended for children. Because these compounds limit the bioavailability of minerals and proteins, reducing them is an important step in improving the nutritional value of quinoa.

Materials

1. White Quinoa Seeds: Obtained from a reliable commercial source.
2. Chemicals for analyzing phytate and tannins, including:
    - Wade Reagent for phytate analysis.
    - Folin Ciocalteu for analyzing tannins.
3. Laboratory equipment: convection oven, water bath, sensitive balance, spectrophotometer, magnetic stirrer, test tubes, vortex, centrifuge, home mill, micropipette

Thermal Processing Methods

The quinoa seed samples were divided into three groups:

1. Control: No heat treatment.
2. Boiling: Quinoa seeds were blanched in boiling water at 100°C for 20 minutes, After boiling, the seeds were drained and dried in an oven at 150°C for 2 hours, to ensure the removal of excess moisture. The dried samples were then milled using a household mill to obtain quinoa flour.
3. Roasting: The seeds were roasted in a non-stick metal skillet over medium heat (approximately 150-160°C) with continuous stirring for 15 minutes, then the sample was ground using a household mill.

4. CHEMICAL ANALYSIS METHODS

Determination of Phytic acid

Preparation of the solutions used :

1. extraction solution: HCl extraction solution (2.4%) was prepared by adding 5.7 ml of 35.4% concentrated HCl solution to distilled water in a 100 ml volumetric flask and completing the volume to the mark using distilled water.
2. Wade reagent: Prepare by mixing 0.3% sulfosalicylic acid + 0.03% (30 microliters) of aqueous ferric chloride $FeCl_3.6H_2O$ (60% concentration) .
3. Standard sodium phytate solution: Prepare by dissolving 11.2 mg of Sodium Phytate (Sigma, St Louis, MO, USA) in a 100 ml volumetric flask and complete the volume to the mark using distilled water.

Procedure

Phytic acid was estimated according to the method described by Latta and Eskin (1980) and referred to by [21], with minor modifications (2015), with minor modifications in the method (quantities were multiplied by 10 times). The method was summarized by weighing a 500 mg sample of flour and each stage (hour) of quinoa flour and then adding 10 ml of extraction

solution to the samples in the tubes intended for this purpose (for the purpose of precipitation of inorganic phosphorus and other impurities) and leaving the samples for extraction for (18) hours on a magnetic shaker. Then the sample was centrifuged at 10,000 r/min for 20 minutes, equivalent to (11180 Xg) at a temperature of 25 °C, then the filtrate was separated and added to other tubes containing (1) g of table salt (for the purpose of concentrating inositol in the solution) and mixed well with an electric vortex mixer to ensure the dissolution of the salt, then the tubes were subjected to freezing at a temperature of (20-) C for 60 minutes to precipitate all components that could interfere with the colorimetric reaction, then dissolve the tubes under liquefaction water and repeat the centrifugation process under the same conditions. (1) ml of the filtrate was withdrawn and diluted (25) times with distilled water, then (3) ml of this diluted solution was withdrawn and mixed with (1) ml of pink Wade reagent prepared for each tube, and the intensity of the pink color of the diluted tubes was measured in the spectrophotometer at a wavelength of 500 nm, and the amount of phytate was calculated after fixing the readings from the spectrophotometer in the straight line equation resulting from the standard curve of sodium phytate y=4.7261x+0.005.

Y: absorbance value

X = Concentration

Estimation of tannins:

The total tannin content of the extracts under study was estimated according to the method presented by [22], with some modification (the sample was not diluted to 100 mL as in the original method but to 10 mL because the color was clearly visible at this limit). Based on the tannic acid standard curve.

1. Extraction solution: Prepare two types of extraction solutions (alcoholic and aqueous):
    a. Aqueous extraction: Using distilled water as the extraction medium to extract water-soluble phenolic compounds (polarity).
    b. Alcoholic extraction: A 70% ethyl alcohol solution was made by mixing 700 ml of concentrated 99.9% alcohol with distilled water in a 1000 ml flask and then storing it in the refrigerator.
2. Standard tannic acid solution at a concentration of 1 mg/mL: Dissolve 10 mg of tannic acid in an appropriate amount of distilled water, and after complete dissolution, transfer to a 10 ml volumetric flask and complete the volume to the mark using distilled water to a final concentration of 1 mg/mL.
3. Folin-Ciocalteu reagent solution (FCR): Also known as Folin-Denis reagent, it is a mixture of phosphomolybdate and phosphotungstate used in the assay of phenolics and phenolic antioxidants and is labeled by the calic acid equivalent method. It was prepared at a concentration of N/1 by diluting commercial reagent N/2 with an equal volume of distilled water and transferred to an opaque vial and stored in the refrigerator at 4°C until use, noting that it should remain golden in color and should not be used if it turns olive green. 13:23
4. $NaCO_3$ sodium carbonate solution with a concentration of 7%: Prepare by dissolving 7 g of sodium carbonate in an appropriate amount of distilled water, and after complete dissolution, transfer to a 100 ml volumetric flask and complete the volume to the mark. 13:30
5. Preparation of the form: The method described by [23] and [24] for the extraction of tannins from quinoa flour was followed with some modification by preparing two types of extracts (alcoholic and aqueous) [at 60 °C and (4:1 f/v)] for both solutions so that the final concentration was 250 mg/ml. 10 g of flour was weighed after passing through a No. 50 sieve into pre-labeled 50 ml plastic tubes, and 40 ml of the solutions prepared in (1.a) and (1.b) were added separately. the tubes were sealed and mixed well with an electric mixer and incubated in a water bath at 60°C for 20 minutes. The tubes were centrifuged at xg 3500 for 10 minutes; the tannin-containing solvent layer was separated and transferred to new, clean, pre-weighed, and labeled 50 mL tubes and stored in the refrigerator until assays were performed.

Procedure

1. I used the standard solution (two standard tannic acid solutions at a concentration of 1 mg/mL): Dissolve 10 mg of tannic acid in an appropriate amount of distilled water, and after complete dissolution, transfer to a 10 ml volumetric flask and complete the volume to the mark using distilled water for a final concentration of 1 mg/ml. Prepare a series of dilutions containing 20-200 mcg/mL of tannic acid, and complete the volume to 0.5 mL using distilled water in 10 mL test tubes in two replicates per volume.
2. Add 2.5 mL of Folin's reagent solution and shake with an electric mixer. 3. Add 5 mL of 7% sodium carbonate solution.
3. Complete the volume to 10 mL by adding 2 mL of distilled water.
4. Incubate the tubes in a 25°C water bath for 20 minutes.
5. The optical absorbance was read at a wavelength of 765 nm for all dilutions after zeroing the apparatus with

distilled water or alcohol (depending on the extract), then subtracting the reading result for each concentration of the comparison tube solution 0.5 Blank ml water or alcohol (2.5 ml reagent + 5 ml sodium carbonate), and calculating according to the straight line equation of the standard curve used to estimate tannins y=0.0043x + 0.0104, which was calculated according to the straight line equation of the standard curve used in the estimation of tannins.

Y : absorbance value

X: concentration

Statistical Analysis

1. The analysis was conducted using SPSS software, employing a one-way ANOVA.
2. One-way ANOVA is employed to assess the significance of differences among samples.
3. Tukey's test is employed for dimensional comparisons in the presence of significant differences.
4. Statistical significance was established at $p < 0.05$.

5. RESULTS AND DATA ANALYSIS

Phytate and tannin content of quinoa flour after heat treatments

Results will be presented on the effect of heat treatment (boiling and roasting) on the concentrations of two anti-nutritional factors in quinoa flour: Phytate and tannins. All results are shown as mean ± standard deviation from three replicates (n = 3), and as shown in Table 1 below, which contains the data obtained from the equation of the straight line of the standard curve.

Table 1: Concentrations of Phytates and Tannins Under Various Processing Methods

Treatment	Phytates	Tannins
Untreated	5239	794.8
Untreated	5240	794.79
Untreated	5241	794.78
Boiling	4835	720.84
Boiling	4827	718.9
Boiling	4843	722.75
Roasting	4325	518.51
Roasting	4320	520.66
Roasting	4329	519.7

Table 1 presents the average concentrations of phytate and tannins in quinoa flour after subjecting it to three different heat treatments: unprocessed, blanching, and roasting. The data indicate that untreated quinoa has the highest levels of phytate (mean ≈ 5240) and tannins (≈ 794.79), reflecting its natural content of anti-nutritional compounds. After blanching, a significant decrease in these concentrations was observed, with the average phytate dropping to ≈4835 and tannins to ≈720.83, which is attributed to the solubilization of some compounds in water during wet cooking. In the case of roasting, the lowest values were recorded for both compounds, with phytate averaging ≈4325 and tannins averaging ≈519.62, indicating that dry heat is effective in breaking or inactivating the chemical bonds of these compounds. Figure (1) This regression plot shows the effect of successive heat treatments on the concentration of phytate and tannins in the studied sample, where a gradual decrease in the concentration of both phytate (represented by the bars and blue line) and tannins (represented by the bars and orange line) is observed as the treatment progresses. This pattern indicates that the heat treatments lead to the decomposition or disintegration of these compounds, which is reflected in their gradually decreasing amounts. This is due to the sensitivity of these compounds to heat, as high temperatures cause changes in their chemical structure, reducing their bioactivity and effect as anti-nutritional compounds. Thus, heat treatment is an effective way to improve the nutritional value of plant foods by reducing the content of compounds that inhibit nutrient bioabsorption.

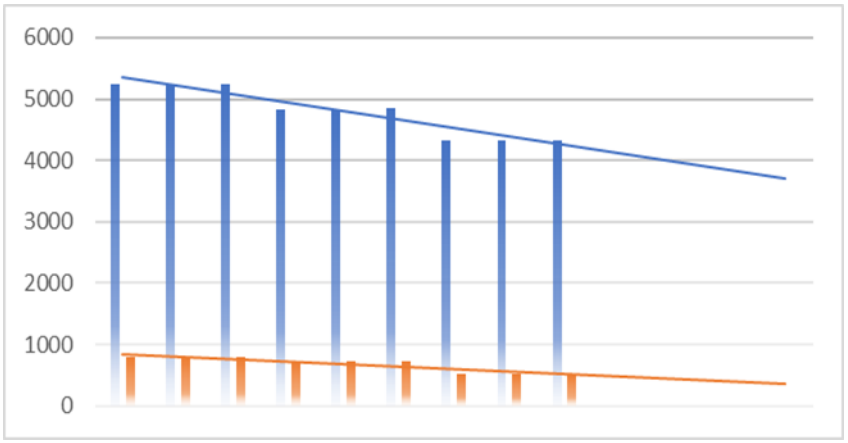

Figure (1)Thermal Processing Effect on Phytates and Tannins Levels – Trend Analysis Chart

Phytate Content (mg/100g)

Table 1 shows the effect of heat treatments on the phytate content of quinoa flour. The untreated sample recorded the highest mean of 5240 mg/kg, with a low standard deviation (±1), indicating a clear homogeneity in the results. When the sample was subjected to the blanching process, the average phytate decreased to 4835 mg/kg, a decrease of approximately 7.7%, due to the dissolution of some of the phytate compounds in the blanching water. Roasting resulted in a greater decrease in the average phytate, reaching 4323 mg/kg, a reduction of about 17.5% compared to the raw sample, with a standard deviation of ±7.211. These results reflect that both treatments reduced the level of phytate in quinoa flour, which may improve the nutritional value of the flour and increase its suitability for use in foods intended for children, without causing significant loss of essential nutrients.

Table 1: Effect of Thermal Treatments on Phytate Content

Phytates	Mean	Std. Deviation	Std. Error	Minimum	Maximum	
Untreated	**5240**	**1.00**	**0.577**	**5239**	**5241**	
Boiling	**4835**	**8.00**	**4.619**	**4827**	**4843**	
Roasting	**4323**	**7.21**	**4.163**	**4315**	**4329**	
Total	**4799.33**	**398.01**	**132.67**	**4315**	**5241**	

Source: Researcher's work using SPSS.

Tannin Content (mg/100g)

Table 2 showed how different heat treatments affected the amount of tannins, which are compounds that can lower the nutritional value of food. The results indicate that the untreated samples had the highest amount of tannins, averaging 794.79 with a very small standard deviation of 0.01, showing that the values were very similar and did not vary much. In the case of chard, the average tannins decreased to 720.83, followed by an increase in variability (standard deviation = 1.93), suggesting a moderate effect of the moist treatment on tannin reduction. However, the roasting results demonstrated a more significant reduction in tannin concentration, with a mean of 519.62. This underscores the efficacy of dry heat in the reduction of these compounds. These results demonstrate that the content of tannins is substantially influenced by the type of thermal treatment, with roasting demonstrating a higher efficacy than blanching. This information can be used to enhance the nutritional properties of plant products.

Table 2: Effect of Thermal Treatments on tannin Content

Tannins	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Untreated	**794.79**	**0.0100**	**0.00577**	**794.78**	**794.80**
Boiling	**720.83**	**1.92502**	**1.11141**	**718.90**	**722.75**
Roasting	**519.62**	**1.07705**	**0.62183**	**518.51**	**520.66**
Total	**678.41**	**123.3295**	**41.1097**	**518.51**	**794.80**

Source: Researcher's work using SPSS.

Statistical analysis of the effect of heat treatments on antinutrients in quinoa flour.

Homogeneity of variance test (Levene's Test)

Before conducting one-way analysis of variance (ANOVA), Levene's test was performed to check the homogeneity of variance between the different treatment groups. The test results showed that the p value was greater than 0.05, indicating that the variance differences between the groups were not significant, and thus the homogeneity of variance condition was met, allowing ANOVA to be used to analyze the differences between the means.

Table 3: Test of Homogeneity of Variances

Anti-nutritional components	Levene Statistic	df1	df2	Sig.
Phytates	**1.784**	**2**	**6**	**.247**
Tannins	**2.387**	**2**	**6**	**.173**

Source: Researcher's work using SPSS

Levene's test for homogeneity of variances in Table 3 shows that there is no statistical significance for the difference of variances between groups (untreated, boiled, roasted) for both phytate ($p = 0.247$) and tannins ($p = 0.173$), as the p-value values were above the 0.05 significance level, confirming the homogeneity of variance and justifying the use of conventional ANOVA to compare means without the need for statistical corrections.

One-Way ANOVA

One-way analysis of variance (ANOVA) was used to evaluate the effect of different heat treatments (no treatment, blanching, roasting) on the concentration of tannins. The results showed significant differences between the three groups, with the F value being statistically significant ($p < 0.05$). This indicates that the type of heat treatment has a significant effect on the concentration of tannins and phytates.

Table 4: Results of the One-Way ANOVA

Dependent Variable		Sum of Squares	df	Mean Square	F	Sig.
Phytates	**Between Groups**	**1262300.222**	**2**	**631150.11**	**22188.871**	**.000**
	Within Groups	**170.667**	**6**	**28.444**		
	Total	**1262470.889**	**8**			
Tannins	**Between Groups**	**121670.899**	**2**	**60835.449**	**37507.727**	**.000**
	Within Groups	**9.732**	**6**	**1.622**		
	Total	**121680.630**	**8**			

Source: Researcher's work using SPSS

Table (4) shows the results of one-way analysis of variance (ANOVA) for two levels of plant compounds: Phytates and

Tannins. The results show that there are very high significant differences between the groups for both phytates and tannins, as the F value was very high (22188.871 for phytates and 37507.727 for tannins) with a statistical significance value (Sig.) of 0.000, indicating that the differences between the groups are not random but statistically significant. This indicates that the independent variable used in the study (e.g. treatment type or sample) has a significant effect on the concentration of both phytate and tannins. Also, the intra-group variability was relatively low, which enhances the reliability of these between-group differences.

Tukey's Multiple Comparison Test

To ascertain the position of the differences between treatments, the Tukey HSD test was applied. The results showed that the differences between "roasting and blanching" and "roasting and no treatment" were statistically significant, while the differences between "blanching and no treatment" were not. This indicates that roasting resulted in a greater reduction in tannins compared to the other treatments**.**

Table 5: Tukey's Multiple Comparison Test

Dependent Variable	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Phytates	Untreated	Boiling	405.00000*	4.35465	.000	391.6387	418.3613
		Roasting	915.33333*	4.35465	.000	901.9721	928.6946
	Boiling	Untreated	-405.0000-*	4.35465	.000	-418.3613-	-391.6387-
		Roasting	510.33333*	4.35465	.000	496.9721	523.6946
	Roasting	Untreated	-915.3333-*	4.35465	.000	-928.6946-	-901.9721-
		Boiling	-510.3333-*	4.35465	.000	-523.6946-	-496.9721-
Tannins	Untreated	Boiling	73.96000*	1.03985	.000	70.7694	77.1506
		Roasting	275.16667*	1.03985	.000	271.9761	278.3572
	Boiling	Untreated	-73.96000-*	1.03985	.000	-77.1506-	-70.7694-
		Roasting	201.20667*	1.03985	.000	198.0161	204.3972
	Roasting	Untreated	-275.1667-*	1.03985	.000	-278.3572-	-271.9761-
		Boiling	-201.2067-*	1.03985	.000	-204.3972-	-198.0161-
*. The mean difference is significant at the 0.05 level.							

Source: Researcher's work using SPSS

Table (5) shows the results of Tukey's post hoc Tukey's post hoc test for one-way analysis of variance (ANOVA) to determine significant differences between pairs of heat treatments (no treatment, blanching, roasting) for Phytates and Tannins.

For Phytates, the results show significant differences (p = 0.000) between all three pairs of treatments. The roasting treatment showed a significant decrease compared to no treatment (difference -915.33) and blanching (difference -510.33), indicating that roasting was more effective in reducing phytate concentration.

As for Tannins, the differences were also statistically significant between all pairs, as indicated by the "Sig." values (all = 0.000). Roasting treatment resulted in a significant decrease in tannins compared to no treatment (difference -275.17) and blanching (difference -201.21), while the differences between no treatment and blanching were lower (73.96). This indicates that roasting was the most effective thermal factor in reducing tannins and phytate levels compared to the other treatments.

6. CONCLUSIONS

This study yielded significant results that strongly support the alternative hypothesis (H_1) and refute the null hypothesis (H_0). The results demonstrated that heat treatments significantly affect the levels of anti-nutritional compounds in quinoa flour. These results confirmed the findings of many previous studies in this field.

Statistical analysis showed a significant decrease ($p < 0.05$) in phytate and tannin content after heat treatment. Phytate concentration decreased from 5240 mg/kg in untreated samples to 4835 mg/kg after boiling (7.7%) and 4325 mg/kg after

roasting (17.5%). Tannins diminished from 794.8 mg/kg to 720.8 mg/kg during boiling (9.3%) and to 519.6 mg/kg after roasting (34.7%).

Roasting proved more efficacious than boiling in diminishing these chemicals, aligning with the findings of [5]. High dry heat causes the dissolution of more permanent chemical bonds, whereas boiling depends on the gradual diffusion of chemicals into water. Tukey's test revealed significant differences ($p = 0.000$) among all treatment groups.

A notable decrease in phytates suggests a possible enhancement in iron and zinc absorption by 20 to 40%, as indicated by [13]. Decreased tannins increase sensory attributes by diminishing bitterness and astringency, hence increasing children's food acceptability, as corroborated by [10].

Notwithstanding these favorable outcomes, it is important to acknowledge that heat treatments may adversely impact some heat-sensitive nutrients, including B vitamins, as shown by [6]. Consequently, next research recommends examining the ideal equilibrium between time and temperature, as well as evaluating other processing techniques, including fermentation and roasting in conjunction.

This work establishes a robust scientific foundation for the development of enhanced quinoa-based infant feeds, highlighting that roasting is the most effective method for minimizing anti-nutritional chemicals. Nonetheless, further research is required to refine processing parameters and evaluate long-term health implications..

Recommendations

1. Implement roasting at 150-160°C for 15 minutes as the ideal method to reduce anti-nutritional chemicals while preserving nutritional content.
2. Examine the impact of varying temperatures (120-180°C) and processing durations to achieve a balance between reducing antinutrients and maintaining heat-sensitive nutrients.
3. Assess the efficacy of integrating fermentation and roasting to improve the reduction of phytate and tannin levels.
4. Evaluate novel technologies, including irradiation and enzymatic therapy, as substitutes for traditional therapies.
5. Create infant food items enriched with toasted quinoa flour to enhance mineral bioavailability. 6. Educate the food sector on the significance of heat treatments in enhancing the quality of pseudo-grain products.

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