EVALUATION OF TEXTURE, COLOR, AND CHEMICAL COMPOSITION OF LOW-FAT CHICKEN NUGGETS FORTIFIED WITH QUINOA

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Abstract

Superfood quinoa can be utilized to produce novel, healthful meat products that are crucial for lowering the risk of chronic illnesses. Four low-fat, konjac-based nuggets fortified with 10% to 40% quinoa, viz., the control (without quinoa), were assessed for their textural properties and color chromaticity. In comparison to the control nugget, incorporating 10% quinoa increased the nugget's textural characteristics, including hardness, cohesiveness, springiness, and chewiness but lower lightness. Increasing to 20% to 40% quinoa made the nuggets have more deteriorated textural characteristics and a darker color. The use of quinoa can increase the fiber content and reduce the protein content of the nuggets. The finding reveals that the optimal addition of 10% quinoa can improve the nugget's texture and fiber content. This provides basic information that has the potential to be scaled up to the industrial level.

Keywords: Chicken nugget, Color, Functional food, Quinoa, Texture

INTRODUCTION

Chicken nugget products generally contain high levels of protein and saturated fat but low fiber content. High consumption is associated with higher risks of health problems, including high blood pressure, diabetes, heart disease, obesity, constipation, colon cancer, and rheumatoid arthritis (Cruz-Requena et al., 2016). The increasing global food fiber market is anticipated to be worth $3174.39 million with a 9.15% Compound Annual Growth Rate (CAGR) from 2022 to 2027 (Mordor intelligence, 2023). However, most consumers have less fiber than the 20–25 g per day recommended by the World Health Organization. The development of high fiber-containing nuggets creates a product with high protein relative to essential nutrients, such as iron, zinc, and B vitamins

(Especially vitamin B12). Simultaneously, the nugget also provides an increasing fiber content, boosting the bowel movement and improving the digestive system (Krzywdzinska-Bartkowiak, Piatek & Kowalski, 2022).

Quinoa (*Chenopodium quinoa*), a superfood containing a high dietary fiber (12–16%) and protein (12–18%) content, has beneficial with good digestion and reduces constipation and colon cancer (Öztürk-Kerimoğlu et al., 2020). Additionally, it is rich in vitamins B2 and B6, potassium, calcium, manganese, linoleic acids, and antioxidants like coumaric acids, quercetin, and kaempferol (Fernández-López et al., 2020). Quinoa can absorb water well and displays diversified functions in various food applications, such as fat- and water-binding capacity, non-caloric bulking effect, gel-forming ability, emulsification, and foaming properties (Alkobeisi et al., 2022). According to the Park et al. (2021) article, quinoa doesn't cause excessive gas and bloating like whole grains, nuts, seeds, and broccoli. It is regarded as a great complement to increasing fiber in diets designed for celiacs because it may be confused with symptoms of celiac disease such as bloating, increased gas, diarrhea, and constipation. Verma, Rajkumar & Kumar (2019) reported the use of quinoa seed flour and amaranth to improve the goat meat nugget quality, while bologna-type sausages showed increasing technological properties as incorporated with black quinoa (Fernández-López et al., 2020).

The functional properties of meat products are related to the extraction of myofibrillar proteins, which are responsible for the development of emulsified meat products, such as gel formation and water-holding capacity, and reducing the separation of water and fat components (Krzywdzinska-Bartkowiak, Piatek & Kowalski, 2022). Currently, there is little information on the impact of quinoa on the quality of chicken nuggets. The objective of this study was to find out the changes in texture and color in low-fat chicken nuggets with various levels of quinoa. Understanding the role of quinoa in meat products will provide a possible way for the development in other food processing products, such as bakery products and noodles.

MATERIALS AND METHODS

1. Materials

Konjac flour (Chengdu Newstar Chengming Bio-Tech Co., Ltd, China), xanthan gum (KELTROL®, CP Kelco, San Diego, CA, USA), and quinoa seed (Arrowhead Mills®, The Hain Celestial Group, Inc., CO, USA). Chicken breast and skin, garlic powder, white soy sauce, salt, black pepper, aniseed, seasoning powder, and shiitake powder (180 – 425 μm) were obtained from local markets.

2. Preparation of cooked quinoa

Quinoa seed was cleaned, added to a saucepan, and covered with water (1 : 2) to cook. The mixture was heated until boiling and then continuously simmered at a low temperature for 15–20 minutes. The cooked quinoa was kept in the refrigerator before use.

3. Processing of chicken nuggets

A low-fat chicken nugget (a non-breaded control) was prepared according to the work of Akesowan (2016) with some modifications. The formulation (total weight basis) included 91% chicken breast, 3% chicken skin, 2.20% water, 1.80% shiitake powder, 0.60% white soy sauce, 0.40% konjac and xanthan (3 : 1) blend, 0.35% salt, 0.30% black pepper, 0.15% seasoning, 0.10% garlic powder, 0.05% anise, and 0.05% clove. Chicken meat and fat were mixed for 30 seconds, followed by shiitake powder, konjac-xanthan blend, white soy sauce, seasoning, garlic powder, anise, and clove. After 1.30-minute mixing, the nugget size (4x2x1 cm^3) was prepared and fried for about 3 minutes (internal temperature about 80°C). In the experimental study, four nuggets containing 10, 20, 30, and 40% quinoa were investigated for their texture and color. The control nugget had no quinoa.

4. Texture profile analysis (TPA)

Samples were measured for the TPA (hardness, cohesiveness, springiness, and chewiness) using a texture analyzer (LRX Plus, Lloyd Instruments, Hampshire, UK) based on Nexygen software.

5. Instrumental color

Samples were measured for instrumental color scales, such as lightness (L*) (0 = black, 100 = white), red/green (a*) (+ = red, − = green), and yellow/blue (b*) (+ = yellow, − = blue). A Color Flex, Hunter Associates Laboratory, Reston, VA) was used in this work.

6. Chemical composition and free amino acid determination

Moisture, protein, fat, ash, carbohydrate, and dietary fiber were determined according to the AOAC (2019) method. The high-performance liquid chromatography method of Vázquez-Orttz et al. (1995) was used to determine free amino acids (FAAs). Eighteen amino acids in regular and tested samples were determined.

7. **Statistical analysis**

A t-test was used for analyzing the difference in means of texture and color data between the control and 10% quinoa nuggets. The Program R (R Foundation for Statistical Computing, Vienna, Austria) was used to analyze the principal component analysis (PCA) based on texture and color values.

RESULTS

1. **Texture profile analysis (TPA)**

The addition of quinoa significantly affected both texture and color of the nuggets. The addition of quinoa (10% to 20%) increased textural characteristics such as hardness, cohesiveness, springiness, and chewiness compared to the control, as shown in Table 1. However, increasing levels of quinoa from 30 to 40% tended to decrease all TPA parameters, as clearly observed in the 40% quinoa nuggets.

Hardness is expressed as the peak force used to crush the nugget between the molars. At 10% quinoa fortification, it showed a greater effect on hardness than cohesiveness (how well a food coheres or sticks together) and springiness (how well a product bounces back after compression) of the nuggets as show in Table 1. When considering chewiness, a term that refers to three different parameters: hardness, cohesiveness, and springiness. It is obvious that chewiness will be substantially associated with hardness.

Table 1 Physical properties of nuggets containing various levels of quinoa.

Parameters	Quinoa substitution (% by chicken meat weight)				
	0	10	20	30	40
Hardness (N)	41.96±1.40^{c}	65.91±1.36^{a}	55.54±2.27^{b}	41.08±1.64^{c}	32.05±1.25^{d}
Cohesiveness	0.41±0.02^{b}	0.52±0.04^{a}	0.47±0.05^{ab}	0.46±0.06^{b}	0.39±0.04^{b}
Springiness (mm)	5.31±0.11^{b}	5.50±1.55^{a}	5.46±1.14^{b}	5.36±0.07^{b}	4.66±1.25^{c}
Chewiness (N × mm)	96.74±2.79^{c}	149.29±4.79^{a}	122.77±4.14^{b}	105.40±5.58^{bc}	68.35±3.25^{d}
L^* value	63.85±0.28^{a}	62.45±0.44^{b}	61.00±0.35^{bc}	60.42±0.28^{c}	59.42±0.71^{c}
a^* value	1.78±0.11^{a}	1.62±0.09^{b}	1.38±0.14^{c}	1.28±0.20^{c}	1.12±0.10^{c}
b^* value	11.65±0.82^{a}	11.17±0.95^{a}	11.74±0.52^{a}	11.68±0.64^{a}	11.21±0.44^{a}
Hue (angle)	81.75±1.23^{c}	82.25±1.41^{c}	83.043±0.98^{b}	83.58±1.07^{ab}	84.83±1.64^{a}
Chroma	11.82±0.78^{a}	11.38±0.88^{a}	11.76±1.30^{a}	11.68±1.26^{a}	11.21±1.18^{a}

Means with different letters within a row are significantly different (P<0.05)

2. Instrumental color

Color is a visual parameter that influences consumer acceptance. Table 1 shows that increasing quinoa levels from 10% to 40% significantly decreased lightness (L*) and redness (a*) in the nuggets. Still, the yellowness (b*) was comparable to the control nugget. The hue angle, a parameter expressing the color tonality of the nuggets, tended to increase with increasing quinoa from 10% to 40%.

3. Chemical composition

Figure 1 shows the chemical composition of the 10% quinoa nuggets showing the decrease in protein and fat content ($P<0.05$), but moisture, ash, fiber, and carbohydrate content were increased ($P<0.05$).

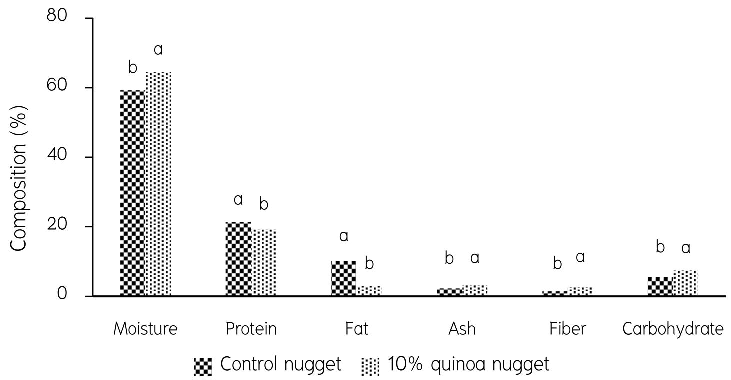

Figure 1 Chemical composition of the control and 10% quinoa nuggets. Different letters are significantly different regarding formulation ($P<0.05$).

4. Free amino acids determination

The quantity of FAAs in the control and 10% quinoa samples is shown in Figure 2a. Most FAAs found in the 10% quinoa nugget are less than those in the control, except for the content of leucine, which is obviously over. Additionally, it was observed that the high amount of Glu in the 10% quinoa nugget is close to that in the control. When considering the taste components of peptides in Figure 2b, the MSG-like (Asp and Glu) and sweet (Ala, Gly, Pro, Ser, and Thr) amino acids did not differ between the nuggets. While the bitter taste components (Arg, His, Ile, Leu, Met, Phe, Try, and Val) were decreased, the tasteless components (Lys, Tyr, and Cys) were increased in the 10% quinoa sample (Vázquez-Orttz et al.,1995).

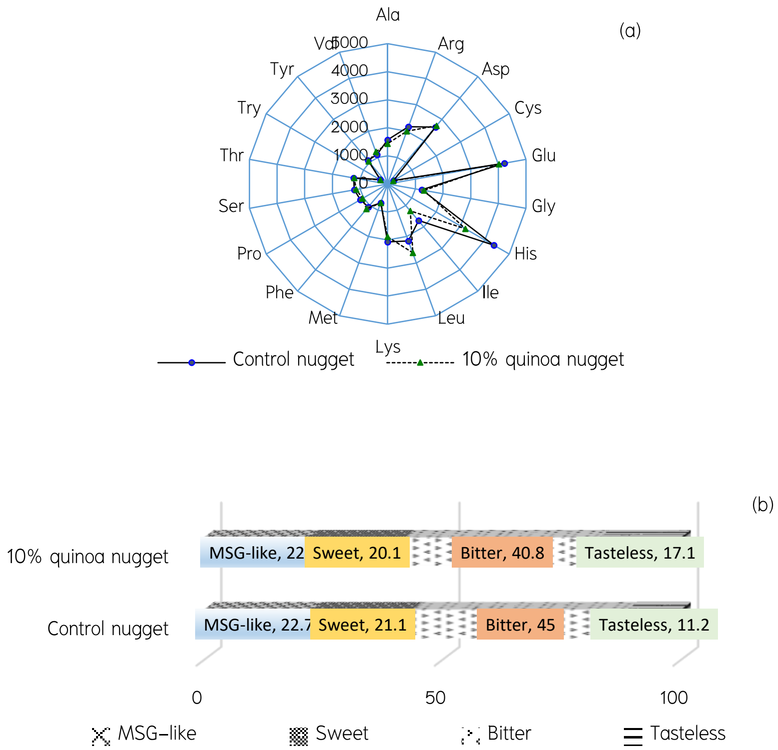

Figure 2 Amino acids analysis of the control and 10% quinoa nuggets: (a) free amino acids content and (b) taste component: MSG-like taste = Asp+Glu; sweet taste = Ala+Gly+Pro+Ser+Thr; bitter taste = Arg+His+Ile+Leu+Met+Phe+Try+Val; and tasteless = Lys+Tyr+Cys.

5. Principal component analysis (PCA)

According to Figure 3, Dim 1 explained 62.16% of the observed variation, while Dim 2 explained 26.32% of the observed variation. The high cumulative value of 88.48% indicates that consumers can reliably and satisfactorily distinguish between different nuggets. The textural characteristics (hardness, cohesiveness, springiness, and chewiness) and color chromaticity (L*, a*, and b*) could be used to discriminate the tested nuggets into two clusters: the first cluster contains the control and 10% to 30% quinoa nuggets, while the second cluster only comprises the 40% quinoa nuggets, as shown in Figure 3a-b. Instead of analyzing many variables, PCA analysis will focus on Dim 1, where springiness and hue value have a positive correlation of 0.94

and a negative correlation of -0.94, respectively. Dim 2 nonetheless demonstrated a positive correlation with cohesiveness (0.70) and a negative correlation with yellowness (-0.73).

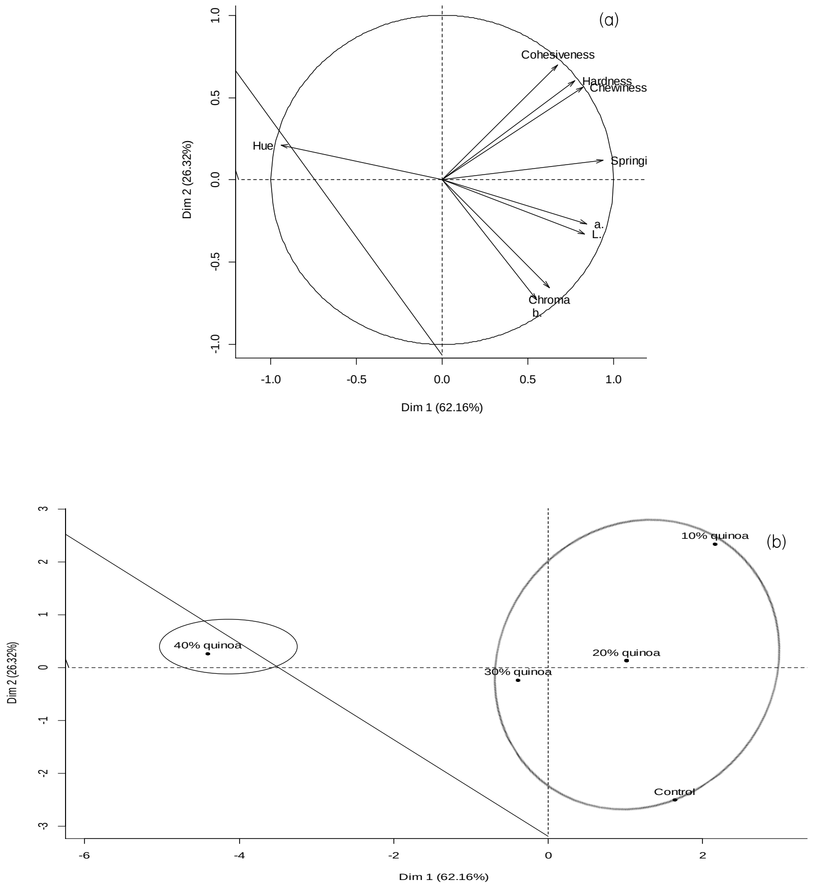

Figure 3 Principal component analysis of nuggets with various quinoa levels: (a) projection of variables and (b) projection of samples.

DISCUSSION

1. Texture profile analysis (TPA)

The addition of quinoa has a significant impact on the nuggets' texture. This is due to quinoa's ability to absorb water and perform a variety of functions in various food applications, such as fat- and water-binding capacity, non-caloric bulking effect, gel-forming ability, emulsification, and foaming properties (Elleuch et al., 2011). It was consistent with Öztürk-

Kerimoğlu et al. (2020), who explained that the quinoa has a high-water affinity and thickens meat batter in a way that helps retain water molecules and slows down the coalescence of fat globules. This could subsequently increase the stability of the meat emulsion, resulting in a harder nugget. Hardness is expressed as the peak force used to crush the nugget between the molars.

The hydrated quinoa might create a highly water- and fat-binding emulsion matrix that helps to stabilize the rheological batter (Lee & Chin, 2019). It was in line with the Öztürk-Kerimoğlu et al. (2020) work, which revealed the higher cohesiveness in beef sausages with added 5% quinoa flour was possibly due to the high dietary fiber content of quinoa. This influences the protein-protein interactions, strengthening the quinoa's spongy network and increasing the compression of the sample. Verma, Rajkumar & Kumar (2019) indicated that the interaction of fiber and rice flour could lead to strong viscoelastic properties and a higher oil absorption capacity. The rice flour-quinoa fiber interactive part would provide an effective binder, improving the TPA characteristics.

The phenomenon might be influenced by the charged amino acid lysine found in quinoa, which may increase the myofibrillar proteins (glutamic acid, lysine, and aspartic acid) to reinforce the protein gel matrix. Sayas-Barberá et al. (2021) reported that meat patties containing black quinoa (High water-binding capacity) during freezing storage had better emulsion stability and rheological characteristics, relating to better textural characteristics. Food with high chewiness implies a harder texture, requires more energy to chew before swallowing, or has more structure. Although the quinoa addition was suitably observed at the 10% level, the amount of quinoa used to replace meat went from 20% to 40%, resulting in poorer nugget textural characteristics. The 40% quinoa nugget showed less textural qualities, namely being softer and less chewy. This is likely because quinoa has excellent water absorption and a low protein content. The more cooked quinoa is used, the less the meat batter emulsifies, resulting in the structure of the nuggets being weaker.

2. Instrumental color

Color is a visual parameter that influences consumer acceptance. Table 1 shows that increasing quinoa levels from 10% to 40% significantly decreased lightness (L^*) and redness (a^*) in the nuggets. Still, the yellowness (b^*) was comparable to the control nugget. These findings show that the nuggets got darker as the quinoa was incorporated, which might be due to the reduction in chicken meat content with increasing brown quinoa content. The lower levels of amino acids, which are involved in the Maillard reaction between reducing sugars and amino acids, result in fewer brown pigments (Kyriakopoulou, Keppler & van der Goot, 2021). Furthermore, the increased quinoa, which has a light brown color when compared to the chicken meat, could be a reasonable issue. Verma, Rajkumar & Kumar (2019) reported that decreased lightness in meat products is correlated with a decrease in meat content.

Redness, or a* value, is a parameter that relates to the myoglobin proportion in meat and meat products. The higher the quinoa was increased, the lower the chicken meat (Myoglobin) was found, as shown in Table 1. Hence, it resulted in a reduction in redness intensity in the nuggets. This was consistent with Sayas-Barberá et al. (2021), who explained a higher loss of water-soluble myoglobin (red) when supplementing hydrolyzed dairy products in poultry meat batters. Differently, Öztürk-Kerimoğlu et al. (2020) observed a decrease in lightness and yellowness but no change in redness values in emulsion-type sausages, which was attributable to the presence of natural yellow in teff flour.

When considering the hue angle, a parameter expressing the color tonality of the nuggets, it increased with increasing quinoa from 10% to 40%, as shown in Table 1. A higher hue value suggests a stronger yellowish tinge because of higher quinoa levels. The chroma value, which measures color saturation, remained steady ($P>0.05$) when quinoa levels increased, as shown in Table 1.

Finally, it can be concluded that the proportion of lean meat and non-meat ingredients, the amount of water and fat, and the types of non-meat components used in the formulation have an impact on how the color of meat products changes (Akesowan, 2021; Kyriakopoulou, Keppler & van der Goot, 2021).

3. Chemical composition

The chemical composition results in Figure 1 denotes that the 10% quinoa nuggets had lower protein and fat, but higher moisture, ash, fiber, and carbohydrate content against the control ($P<0.05$). Changes in these parameters are likely due to the high-fiber quinoa with its high water-holding property, which does swell when cooked. The fat content was about 2.89 g, below 3 g of fat per 100 g of food, thereby allowing the sample to be claimed as a “light” food, besides having 33% less total energy than the regular nugget. Additionally, cooked quinoa contains 4-5 g of dietary fiber per 100 g, and the 10% quinoa nugget (2.72 g) has more fiber than the control nugget (1.45 g) (Öztürk-Kerimoğlu et al., 2020). The product provides at least 10.80%

of the daily value; thus, it can be considered a “good source of fiber” because it contains at least 10% of the daily fiber intake recommended by U.S. food label regulations (Mehta et al., 2015).

4. Free amino acids determination

Overall, the quantity of most FAAs found in the 10% quinoa nugget are less than those in the control, except for the content of leucine, which is obviously higher (Figure 2a). This may be caused by the less meat in the sample, which could have reduced the action of proteases on proteins during food processing, thus decreasing the FAA content in the quinoa sample (Lestari et al., 2022). However, the 10% quinoa nugget provides a high amount of Glu equal to the control, indicating the benefit of this superfood quinoa. This implies that the use of quinoa might slightly affect the umami taste, a taste of monosodium glutamate (MSG) usually occurring in meat products during heat processing. When considering the taste components of peptides in Figure 2b, the MSG-like (Asp and Glu) and sweet (Ala, Gly, Pro, Ser, and Thr) amino acids did not differ between the nuggets. While the bitter taste components (Arg, His, Ile, Leu, Met, Phe, Try, and Val) were decreased, the tasteless components (Lys, Tyr, and Cys) were increased in the 10% quinoa sample (Vázquez-Orttz et al.,1995). Quinoa may be a healthy substitute for a meaty diet because it contains more amino acids.

5. Principal component analysis (PCA)

The PCA method can reduce the complexity of many variables, making it easier to interpret the data and evaluate the quinoa nuggets' quality. The high correlation between independent variables found in Figure 3a can be used to determine the effect of individual variables on the predicted outcome. Therefore, it is suggested that there be more springiness and cohesiveness but less yellow tonality. In Figure 3b, the PCA mapping revealed differentiated samples from those with the best characteristics to those with the least. It was found that the 10% quinoa nugget, which is positioned in the right upper quadrant, is springier and more cohesive but less yellow than the control and the other 20% to 40% quinoa nuggets.

CONCLUSION

The incorporation of quinoa in low-fat nuggets revealed a change in texture qualities, color visualization, and nutritional quality. The 10% quinoa nugget is an optimal formulation, greatly improving in terms of hardness, cohesiveness, springiness, and chewiness and decreasing the nuggets' lightness. However, incorporating the quinoa from 20% to 40% levels declined textural parameters and made the nuggets darker. The finding promotes an understanding of the role of quinoa in the nugget's quality. It provides a feasible way to produce a healthy meat product. Furthermore, it may be a guideline to use other superfoods or high fiber plants in the food products.

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