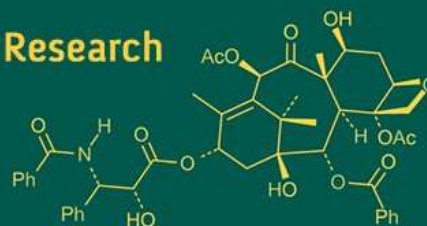
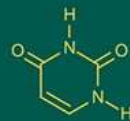
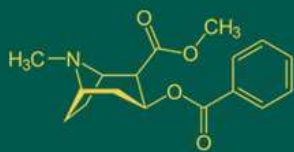


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Chamundeshwari A
Department of Food Science
and Technology, School of
Agricultural Sciences, Malla
Reddy University,
Maisammaguda, Hyderabad,
Telangana, India

Shirisha T
Department of Horticulture,
School of Agricultural Sciences,
Malla Reddy University,
Maisammaguda, Hyderabad,
Telangana, India

Corresponding Author:
Chamundeshwari A
Department of Food Science
and Technology, School of
Agricultural Sciences, Malla
Reddy University,
Maisammaguda, Hyderabad,
Telangana, India

Development of muffins using pseudo cereals and their physicochemical properties

Chamundeshwari A and Shirisha T

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Abstract

The creation and assessment of muffins with quinoa flour for functional enrichment component were the purpose of this research was to study. Along with a control sample, quinoa grains were processed into fine flour and used to muffin formulations (T₁, T₂, and T₃). To ascertain their overall quality and performance, the produced goods underwent extensive analyses, including physicochemical, proximate, morphological, thermal, molecular, sensory, and shelf-life assessments. The proximate composition indicated notable enhancements in the nutritional profile of muffins with quinoa. Samples varied in their energy content, with T₃ having the highest amount (363.6 ± 6.88 Kcal) compared to the control. From $57.48 \pm 0.34\%$ in the control group to $61.17 \pm 0.66\%$ in T₃, the carbohydrate content increased somewhat. T₃ had a significantly higher protein content ($9.83 \pm 0.01\%$) than the control ($7.37 \pm 0.01\%$). In all samples, the fat content showed some degree of stability. While the ash concentration increase was observed in T₃ at $2.35 \pm 0.51\%$, indicating increased mineral content, moisture percentage decreased in treated samples, showing improved shelf stability. T₃ had elevated fiber content, suggesting a higher functional value.

T₃ had somewhat lower L*, a*, and b* values according to color analysis, but it seemed more consistent and aesthetically pleasing. Better eating quality was indicated by texture profile analysis, which showed increased cohesiveness, softness, and decreased gumminess and chewiness in T₃. DSC examination showed better molecular organization and greater heat stability, while SEM analysis showed a dense, compact, and cohesive microstructure with fewer air cells in T₃. Stronger protein-carbohydrate interactions and improved structural integrity in quinoa-based muffins were further validated by FTIR analysis. According to the sensory examination, T₃ nearly matched the control with good marks for color, flavor, taste, and overall acceptability. Good microbiological stability was shown by shelf-life experiments, which showed lower microbial counts under ambient storage relative to the control sample and no growth of yeast or mold under frozen and refrigerated settings.

The T₃ formulation was determined to be the best sample because to its superior nutritional composition, enhanced physicochemical and structural properties, advantageous sensory aspects, and enhanced storage stability. The study clearly shows that muffins prepared with quinoa flour are rich in quality and that adding this value-added ingredient significantly enhances the total product quality, with T₃ being the best-performing formulation.

Keywords: Muffins, pseudo cereals physico-chemical properties

Introduction

In response to the increasing consumer preference for healthier food choices, food industry stakeholders are increasing the standard for their products. Bakery businesses are actively innovating by utilizing new ingredients, specialized additions, and state-of-the-art processing technology to improve product quality and diversify their product portfolios. These developments attempt to provide bakery products new functional, sensory, and health-related properties in order to produce bread and other baked items with particular functional and nutritional qualities.

Quinoa is a pseudocereal originating from Latin America that has gained considerable popularity among consumers in European and international markets. Because of its well-balanced nutritional profile, which includes carbohydrates, high-quality proteins, lipids, minerals, and a variety of bioactive compounds, quinoa has been widely recognized as a promising ingredient for improving the nutritional quality of bakery goods typically made with refined wheat flours.

Quinoa may also improve the ratio of omega-3 to omega-6 fatty acids and increase the percentage of unsaturated fatty acids in baked foods. Quinoa is especially rich in linoleic acid and α -linolenic acid, which are precursors of long-chain polyunsaturated fatty acids (PUFAs), which are important for maintaining human health. Quinoa helps people fulfill the required daily intakes of nutrients like calcium, iron, and zinc because of its lipid profile, high quantities of dietary fibre, and essential minerals. However, in addition to the mineral composition of the diet, the presence of antinutritional compounds such as phytates influences mineral bioavailability. Phytates are known to chelate di- and trivalent minerals, reducing their intestinal absorption.

In addition to their high nutritional fibre content, quinoa and other grain-based wholemeal flours may offer multiple additional health advantages when added to muffin recipes. These benefits include improved gastrointestinal transit, lowered blood cholesterol, and prebiotic effects, among other physiological processes associated with dietary fibre intake. Furthermore, studies have shown that incorporating the outer layers of cereal grains and employing whole grains are effective ways to lower the glycaemic response of baked foods. High glycaemic index (GI) “diets have been strongly associated” to metabolic problems, a higher chance of type 2 diabetes, and a greater incidence of obesity and overweight, highlighting the possible health benefits of adding quinoa to baking recipes. The physical and textural characteristics of doughs made with quinoa seed flour differ considerably from those made just with wheat flour. These differences often result in baked foods with reduced loaf volume, increased stiffness, and denser crumb structures. Earlier studies have indicated that adding up to 25% quinoa seed flour to wheat flour formulations did not negatively affect the acceptability of bread, muffins, or cookies and in certain instances, offered a more palatable flavor profile. It is important to note that baked items created with quinoa seed flour usually exhibit a decrease in specific volume and an increase in hardness.

As a result, adding pseudo-cereal flours can alter the batter's rheology, crumb stiffness, moisture retention, and colour which in turn affects characteristics like chewiness, cohesiveness, hardness, and springiness. Based on the level of substitution and processing circumstances, sensory characteristics like flavor, aroma, mouthfeel, and crumb softness may also change. In comparison to traditional

wheat-based products, muffins enhanced with pseudo-cereals can provide better nutritional content and acceptable sensory quality when properly made. In this regard, the current study's goals were to create muffins with a pseudo-cereal

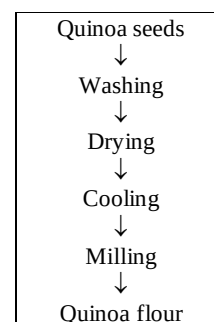
to determine the generated muffins' approximate content and to assess the developed muffins' sensory and textural qualities.

Materials and Methods

Procurement of raw material

For the present research work, the required raw materials were obtained from the local market in Hyderabad: quinoa seeds, baking soda, baking powder, salt, sugar, eggs, butter, oil, milk, and vanilla extract.

Grinding of Quinoa seeds into flour



Proximate analysis

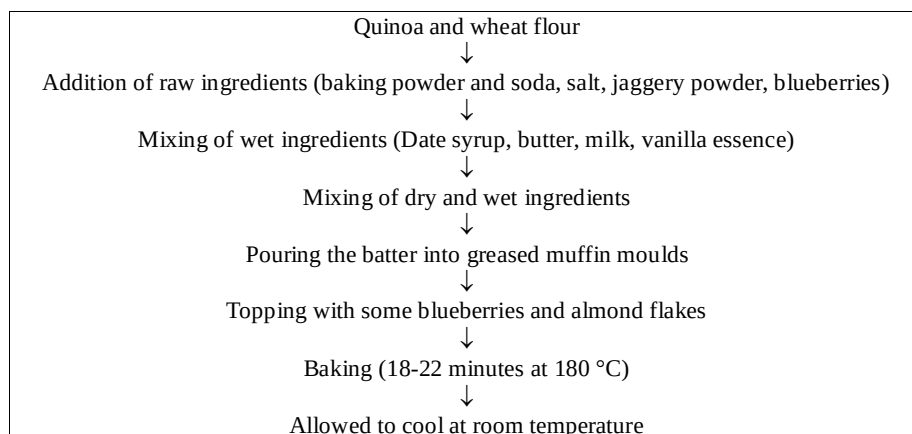
The Moisture content of muffin samples was determined using a hot air oven drying method. Ash content was determined by incinerating the dried sample in a muffle furnace at 550 °C until light grey ash was obtained. The fat content of the muffin samples was determined using the Soxhlet extraction method. Kjeldahl method was used to estimate the protein content of muffin samples.

Development of muffins using Quinoa flour

In the development of muffins, three products labelled T₁, T₂, and T₃, along with a control sample, were created and standardized. Quinoa flour was incorporated into the test samples at different concentrations, as specified in Table 3.1.

Table 1: Formulation of developed muffins using quinoa flour

Ingredients (g)	Control	T ₁	T ₂	T ₃
Wheat flour	40	30	25	20
Quinoa flour	-	10	15	20
Jaggery powder	20	13	13	13
Date syrup	-	13	13	13
Butter	20	13	13	13
Milk	12	15	15	15
Baking powder	2	0.5	0.5	0.5
Baking soda	1	0.5	0.5	0.5
Vanilla essence	1	1	1	1
Blueberries	2	2	2	2
Almonds	2	2	2	2

Methodology for the preparation of muffins using quinoa flour

The muffins were prepared by first combining quinoa flour and wheat flour with the dry ingredients, including baking powder, baking soda, salt, jaggery powder, and blueberries. Separately, the wet ingredients date syrup, butter, milk, and vanilla essence were mixed until a uniform consistency was achieved. The wet mixture was gradually mixed into the dry

ingredients to form a smooth batter. The batter was transferred into greased muffin moulds, followed by topping with additional blueberries and almond flakes. The muffins were baked at 180 °C for 18-22 minutes, following which they were taken out from the oven and permitted to cool at room temperature.



Control

T₁T₂T₃**Fig 1:** Muffins developed using quinoa flour

Color properties

Colour parameters such as lightness, darkness and yellowness (L^* , a^* and b^*) of meat analogues were determined using a colourimeter (Colour flex CX2748, Hunter Lab, USA).

Texture profile analysis

The texture profile analysis of muffins was conducted by evaluating seven textural parameters: hardness, adhesiveness, springiness, cohesiveness, gumminess, chewiness and resilience. Textural properties provided valuable insights into how the plant proteins influenced the eggless muffins textural attributes compared with conventional cookies.

The texture profile analysis of muffins was performed using a Brookfield Texture Analyzer (Model: Ametek Brookfield-CT 100). Data were analyzed with Texture Pro-CT software, following the method established by Jaico *et al.* (2022). Instrumental settings included a pre-test speed of 2 mm/s, a post-test speed of 1 mm/s, a 50 N load cell, and a trigger load of 7 g. The recorded textural parameters were hardness, cohesiveness, gumminess, springiness, and chewiness. Samples were placed on a heavy-duty platform and underwent two analysis cycles to mimic human chewing. The samples were analysed for three times for two compression cycles.

Morphological analysis

Surface features of samples were observed by using scanning electron microscope (FEI Quanta 200 F SEM).

Pulse protein concentrate powder was directly deposited on a plate prior to examination of samples. The accelerating voltage (30 kV) was used for SEM analysis of PPCs. Micrographs were taken at 5009 to 15 0009 magnification at 100-3 μ m.

Thermal properties

Differential scanning calorimetry (DSC, V4.2E, NETZSCH DSC 204F1 Phoenix, USA) was used to estimate the thermal stability of the samples. Samples (8-10 g) were directly placed on aluminium pans (Al crucible with a pierced lid) and heated from 20 to 400 °C at a heating rate of 10 °C/min.

Sensory analysis of developed muffins

The product development process included an organoleptic evaluation assessing key sensory parameters such as flavour, taste, colour, texture, and overall acceptability. The evaluation was conducted with the participation of 59 untrained panellists from the School of Agricultural Sciences, Malla Reddy University, Maisammaguda, Hyderabad.

Statistical analysis

All the data were subjected to statistical analysis to calculate the mean and standard deviation. The values were expected as Mean $\pm$ SD.

Results and Discussion

Proximate analysis of developed muffins

Table 2: Proximate composition of developed muffins

Parameter	Control	T ₁	T ₂	T ₃
Energy (Kcal)	363.6 $\pm$ 6.88	347.29 $\pm$ 8.26	353.10 $\pm$ 11.20	394.2 $\pm$ 5.24
Carbohydrates (%)	57.48 $\pm$ 0.34	59.27 $\pm$ 1.21	60.94 $\pm$ 2.01	61.17 $\pm$ 0.66
Protein (%)	7.37 $\pm$ 0.01	7.49 $\pm$ 0.31	7.41 $\pm$ 0.15	9.83 $\pm$ 0.01
Total fat (%)	10.03 $\pm$ 0.23	10.29 $\pm$ 1.10	10.31 $\pm$ 0.12	10.21 $\pm$ 1.02
Moisture (%)	40.09 $\pm$ 0.10	33.31 $\pm$ 0.31	33.22 $\pm$ 0.12	34.04 $\pm$ 0.04
Ash (%)	2.14 $\pm$ 0.01	2.12 $\pm$ 0.12	2.21 $\pm$ 0.19	2.35 $\pm$ 0.51
Dietary fibre (%)	4.36 $\pm$ 1.05	5.12 $\pm$ 1.02	5.31 $\pm$ 0.12	6.03 $\pm$ 2.01

The above values are expressed as Mean $\pm$ SD (n = 3)

Table 2 presents the proximate composition of the developed muffins and reveals notable variations between the control sample and the quinoa flour incorporated treatments (T₁, T₂, and T₃). The energy content of the muffins varied across formulations, with the control sample recording 363.6 $\pm$ 6.88 Kcal. Among the quinoa-based samples, T₁ exhibited a lower energy value of 347.29 $\pm$ 8.26 Kcal, followed by T₂ with 353.10 $\pm$ 11.20 Kcal, while the T₃ formulation showed the highest caloric value, exceeding both the control 363.6 $\pm$ 6.88 Kcal and the other treatments. Carbohydrate content showed moderate variation, with the control sample containing 57.48 $\pm$ 0.34%, T₁ recording a value of 59.27 $\pm$ 1.21%, and T₂ showing a lower level of 60.94 $\pm$ 2.01%, indicating a relatively balanced macronutrient profile, while T₃ contained 61.17 $\pm$ 0.66. A significant enhancement in protein content was observed in the T₃ sample 9.83 $\pm$ 0.01%, which was considerably higher than that of the control 7.37 $\pm$ 0.01% and the other quinoa-incorporated formulations, namely T₁ 7.49 $\pm$ 0.31% and T₂ 7.41 $\pm$ 0.15%, thereby highlighting the protein-enriching effect of quinoa flour incorporation. Total fat content remained relatively uniform across all samples, with values of 10.03 $\pm$ 0.23% in the control, 10.29 $\pm$ 1.10% in T₁, 10.31 $\pm$ 0.12% in T₂, and 10.21 $\pm$ 1.02% in T₃, suggesting that the

addition of quinoa flour did not exert a significant influence on lipid levels. The moisture content was highest in the control sample 40.09 $\pm$ 0.10%, while reduced levels were observed in the quinoa-based samples, with T₁ at 33.31 $\pm$ 0.31%, T₂ at 33.22 $\pm$ 0.12%, and T₃ at 34.04 $\pm$ 0.04%, indicating comparatively lower moisture in the incorporated formulations. Ash content in the control sample was recorded as 2.14 $\pm$ 0.01%, whereas the quinoa flour-based samples showed values of 2.12 $\pm$ 0.12% T₁, 2.21 $\pm$ 0.19% T₂, and 2.35 $\pm$ 0.51% T₃. The dietary fibre content of the control sample was 4.36 $\pm$ 1.05%, while T₁ and T₂ contained 5.12 $\pm$ 1.02% and 5.31 $\pm$ 0.12%, respectively; the T₃ sample recorded 6.03 $\pm$ 2.01%, indicating a higher dietary fibre content compared to the other treatments, reflecting the enhanced mineral and fibre contribution of quinoa flour. Overall, muffins formulated with a higher proportion of quinoa flour T₃ exhibited improved nutritional quality, particularly with respect to protein, dietary fibre, mineral content, and energy value, thereby demonstrating their potential as a nutritionally enriched bakery product when compared to conventional muffins. These findings are consistent with previous studies reported by Encina-Zelada *et al.*, (2018) ^[18].

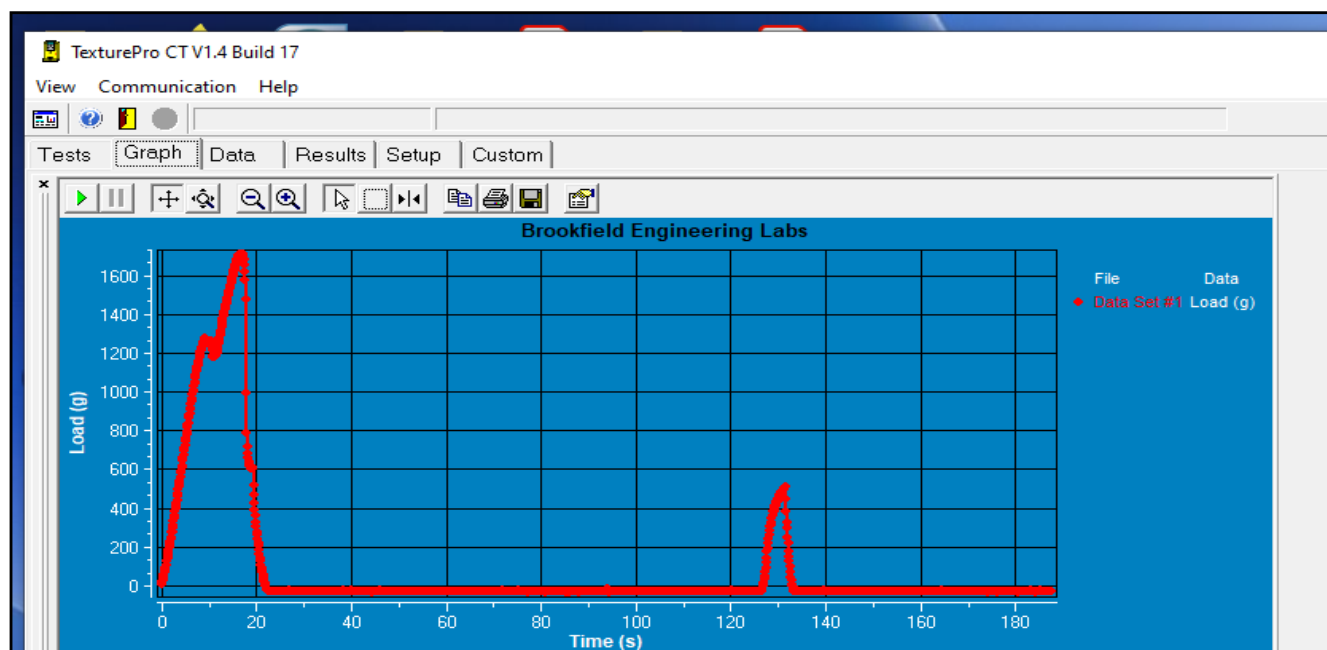
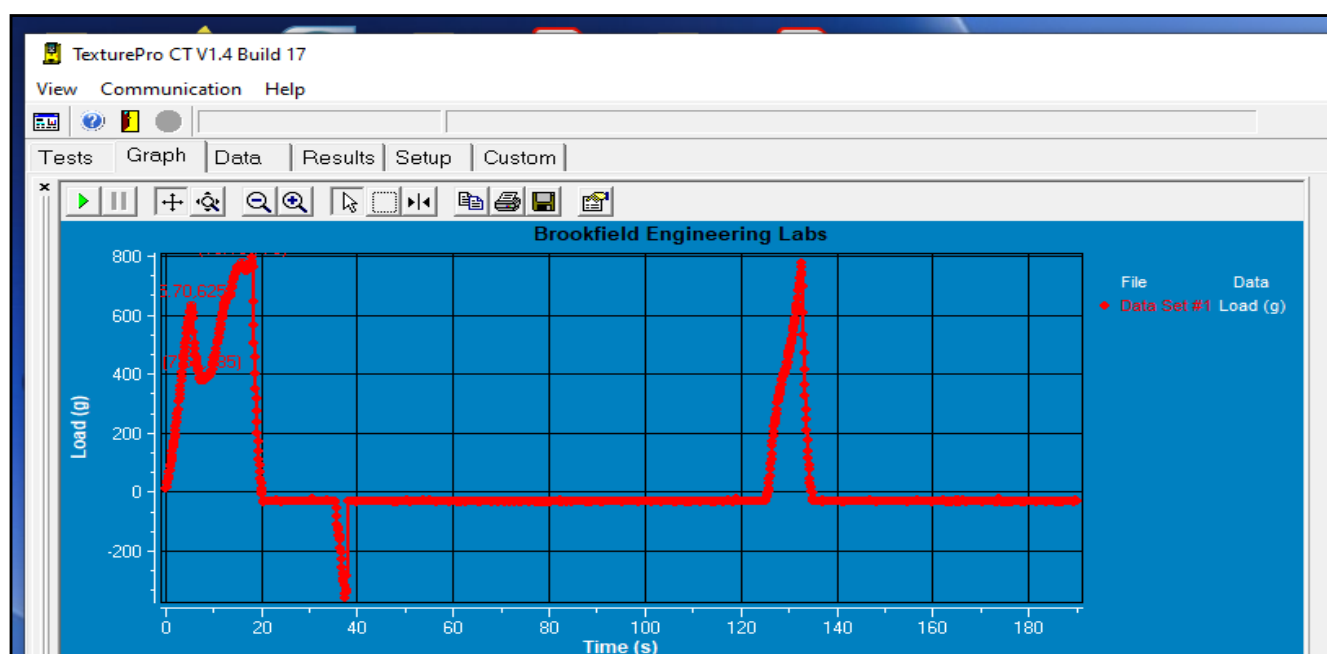


Fig 2: Color analysis of control sample

Fig 3: Color analysis of T₃ sample

Physical analysis of developed muffins

Table 3: Colour parameter of developed muffins

Sample	L*	a*	b*
Control	28.82 ± 1.12	5.11 ± 1.01	17.20 ± 1.40
T ₃	26.48 ± 0.12	4.12 ± 1.12	16.12 ± 1.10

The above values are expressed as Mean ± SD (n = 3).

The produced quinoa flour muffins' color properties are shown in Table 3, which compares the optimized formulation T₃ with the control sample in terms of L* (lightness), a* (redness), and b* (yellowness) values. The results showed that the two samples' color profiles differed somewhat, indicating the impact of adding quinoa flour.

The T₃ sample had a lower L* value of 26.48 ± 0.12, suggesting a slightly darker color, while the control sample had a higher L* value of 28.82 ± 1.12, suggesting a

significantly lighter look. The natural coloring and compositional features of quinoa flour, which tend to give a more appealing baked look, may be responsible for this decrease in lightness in T₃.

The control sample had a redness a* of 5.11 ± 1.01, whereas T₃ had a little lower value of 4.12 ± 1.12, suggesting a modest reduction in red tones. In a similar vein, the control sample's b* value (17.20 ± 1.40) was higher than T₃'s (16.12 ± 1.10), indicating a minor decrease in yellow intensity in the optimized sample.

The T₃ sample showed a more consistent and attractive color, which is frequently linked to better baking quality and customer preference, despite these little decreases in L*, a*, and b* values. T₃'s somewhat darker tone may be beneficial since it could provide the impression that the product is well-baked. The T₃ formulation was chosen as the best-performing sample among the formulas examined since,

overall, the results show that it generated an acceptable and aesthetically pleasing muffin. These results align with earlier research published by Khabeer *et al.* (2018) ^[17].

Table 4: Textural profile analysis of developed muffins

Textural Parameters	Control	T ₃
Hardness (mJ)	90.47 ± 0.82	81.53 ± 11.6
Cohesiveness	0.08 ± 0.04	1.53 ± 0.11
Adhesiveness (mJ)	15.83 ± 5.08	14.30 ± 0.95
Resilience	0.08 ± 0.04	0.06 ± 0.06
Springiness (mm)	5.45 ± 1.68	2.84 ± 0.20
Gumminess (g)	91.33 ± 3.12	9.33 ± 3.06
Chewiness (mJ)	8.07 ± 0.58	0.33 ± 0.06
Fracturability(g)	943.33 ± 13.12	651.67 ± 14.12

The above values are expressed as Mean ± SD (n = 3).

Table 4 The increased quality qualities of the T₃ formulation were indicated by the textural profile analysis of quinoa flour muffins, which showed notable variations between the control and T₃ samples. A softer and more enticing texture was indicated by the T₃ sample's decreased hardness (81.53 ± 11.6 mJ) in comparison with the control sample (90.47 ± 0.82 mJ). The cohesiveness of T₃ was much higher (1.53 ± 0.11) than that of the control (0.08 ± 0.04), indicating that the optimized sample had better internal structure and binding properties.

Compared to the control group (15.83 ± 5.08 mJ), adhesiveness was marginally reduced in T₃ (14.30 ± 0.95 mJ), indicating less stickiness, which is favorable for customer acceptability. T₃ had somewhat lower resilience ratings (0.06 ± 0.06) than the control group (0.08 ± 0.04), suggesting a minor decrease in recovery after deformation. Furthermore, T₃'s springiness decreased from 5.45 ± 1.68 to 2.84 ± 0.20, indicating less elasticity with T₃ 9.33 ± 3.06 showing significantly lower values than the control 91.33 ± 3.12, gumminess was markedly reduced, indicating that the product is less dense and requires less energy to decompose. Additionally, chewiness was considerably reduced in T₃ (0.33 ± 0.06) compared to the control group (8.07 ± 0.58), suggesting easier mastication. Furthermore, fracturability was lower in T₃ (651.67 ± 14.12) compared to the control (943.33 ± 13.12), suggesting a less brittle and more delicate product. Overall, the T₃ sample exhibited improved cohesiveness and textural characteristics, including reduced fracturability, chewiness, gumminess, and hardness. These characteristics show that the T₃ formulation was the most acceptable and optimal sample among the formulations examined, producing a softer, more tasty, and structurally stable muffin. These findings correspond with earlier research published by (Murugkar *et al.*, 2016) ^[18].

SEM (Scanning Electron Microscopy)

A well-developed and continuous microstructural network, typical of gluten-based baked goods, is visible in the SEM micrographs of the control muffin sample made from wheat flour. The structure appears as a moderately compact matrix with unevenly scattered gaps or pores at lower magnification (×300). Gas cells created during batter aeration and expansion during baking are represented by these spaces. Such air pockets contribute to the muffin's desired soft and spongy feel and are a sign of successful leavening.

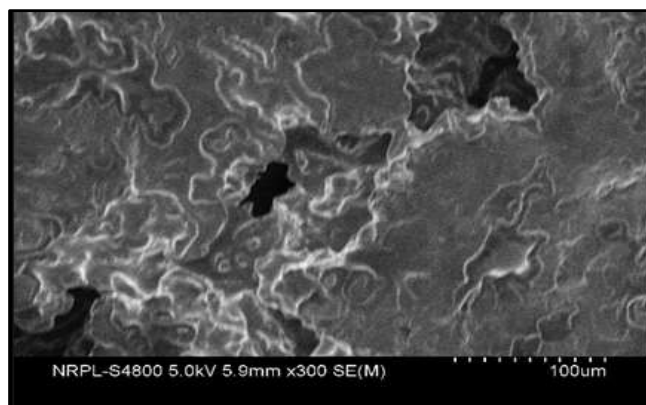


Fig 4: At magnification of × 300

The micrographs clearly show a coherent protein-starch matrix at intermediate magnifications (×600 and ×1.20K). Swollen starch granules are surrounded by a continuous, web-like structure known as the gluten network. This shows that the starch has been properly hydrated, gelatinized, and developed into gluten, all of which contribute to the product's structural integrity. The matrix exhibits little disturbance, indicating that the control sample's internal structure remained intact throughout baking.

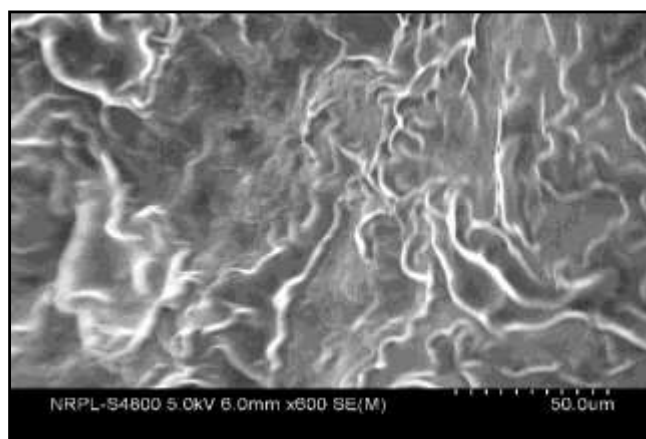


Fig 5: At magnification of × 600

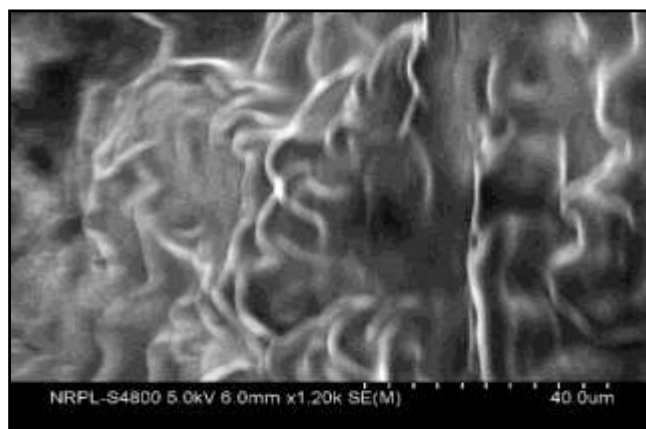
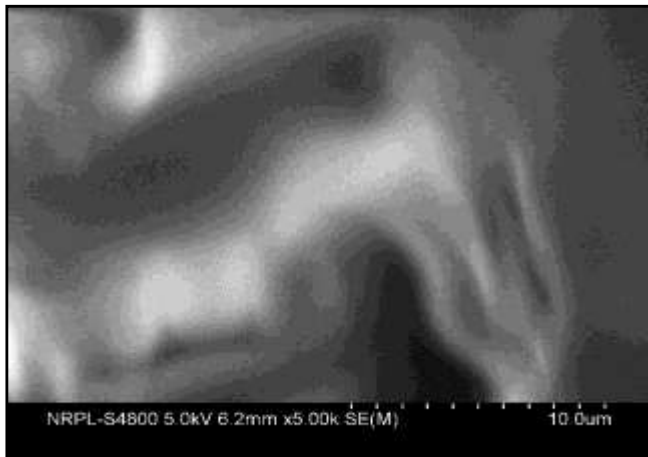
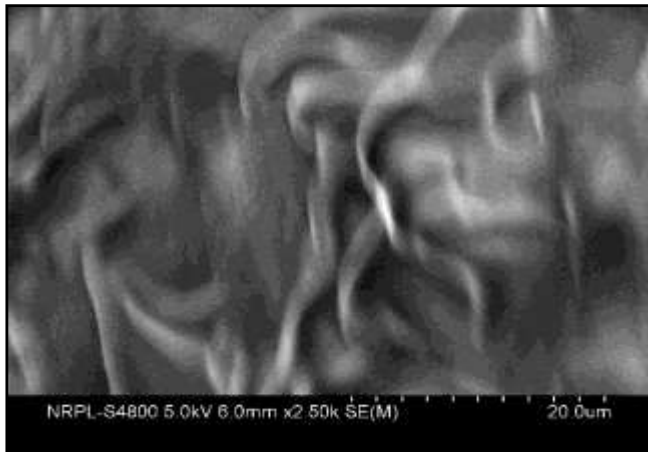


Fig 6: At magnification of ×1200

The surface morphology appears smoother with fewer apparent cracks at higher magnifications (×2.50K and ×5.00K), suggesting a homogeneous component distribution. Because of gelatinization, the borders of the starch granules are less clear and appear to be embedded inside the protein matrix.



Wheat gluten's good binding qualities which are crucial for retaining gas and maintaining product volume are indicated by the absence of obvious fissures or fragmentation. Overall, the SEM analysis confirms that the control muffin sample has a thick, elastic microstructure with well-formed air cells and a continuous gluten network. This structural arrangement is closely related to better textural attributes like cohesiveness, softness, and springiness. The results serve as a reference for comparison with experimental samples and show the crucial role of wheat flour gluten in

producing the proper crumb structure in muffins.

SEM Analysis of T₃ Muffin Sample

The microstructural characteristics of the T₃ muffin sample prepared with quinoa flour were analyzed using scanning electron microscopy at different magnifications (300×, 600×, 1.20k×, 2.50k×, and 5.00k×). The obtained images clearly indicate structural changes that illustrate the influence of quinoa flour incorporation on the internal matrix in comparison with the control wheat-based muffins.

At a lower magnification of 300×, the T₃ sample displayed a relatively compact and continuous matrix with fewer large voids and a more cohesive network. The structure appeared denser due to the reduced porosity and tighter component packing. This suggests that quinoa flour contributes to a more cohesive batter structure during baking.

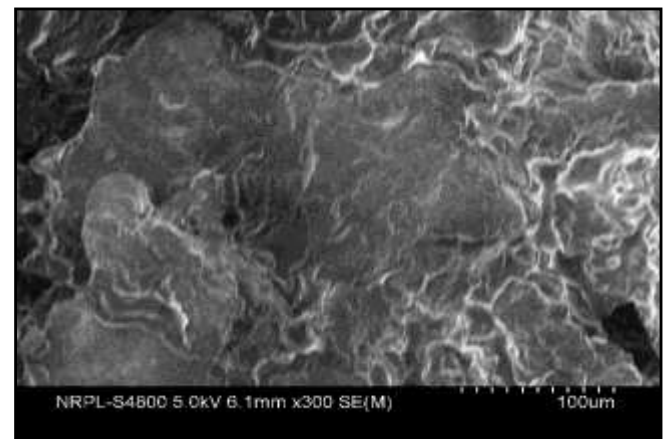


Fig 7: At magnification of ×300

At 600× magnification, the matrix showed interconnected areas with limited air cell development, in contrast to the more open and porous structure often found in wheat-based products. The reduction in pore size and quantity may be due to quinoa's absence of gluten, non-gluten proteins, and dietary fiber, all of which have an impact on gas retention and expansion.

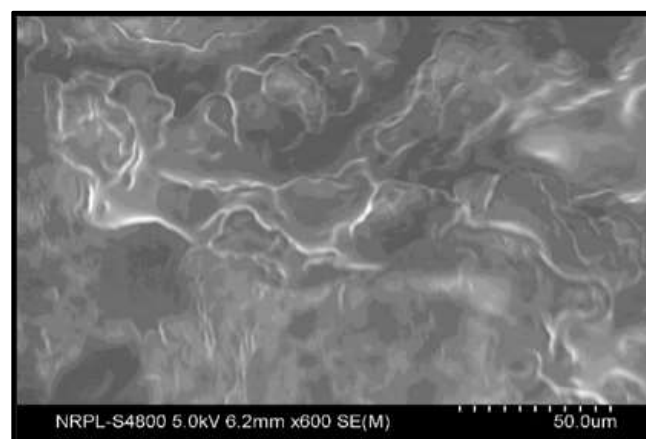


Fig 8: At magnification of ×600

The surface morphology looked smooth with merged granules at intermediate magnification (1.20k×), suggesting substantial interaction between the protein and starch

components and partial gelatinization. Improved binding and consistency within the matrix were suggested by the less clear boundaries between structural pieces.

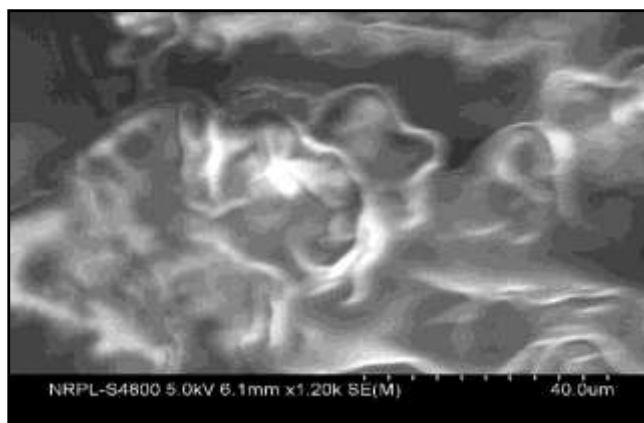


Fig 9: Atmagnification of×1200

The SEM pictures showed a highly homogeneous and cohesive structure with few voids and cracks at higher magnifications (2.50k× and 5.00k×). The continuous phase that the starch granules appeared trapped in was probably

created by interactions between proteins and starch. Although it may also be linked to a harder texture, this dense microstructure suggests better structural integrity.

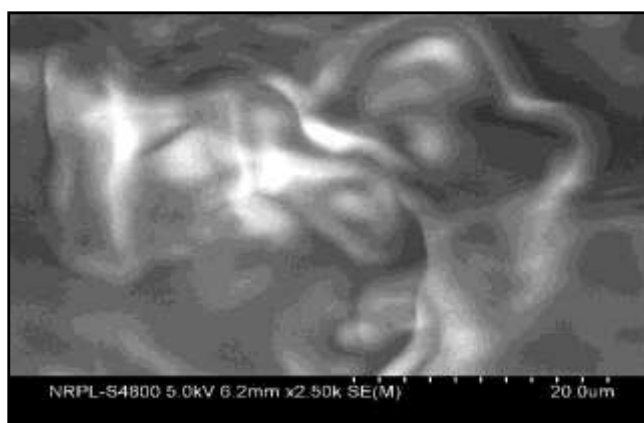


Fig 10: Atmagnification of×2500

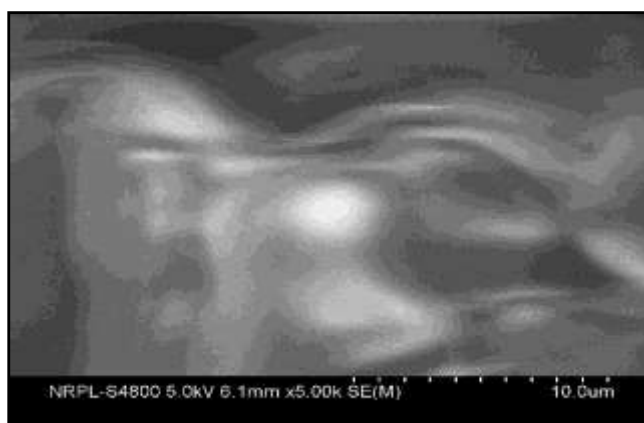


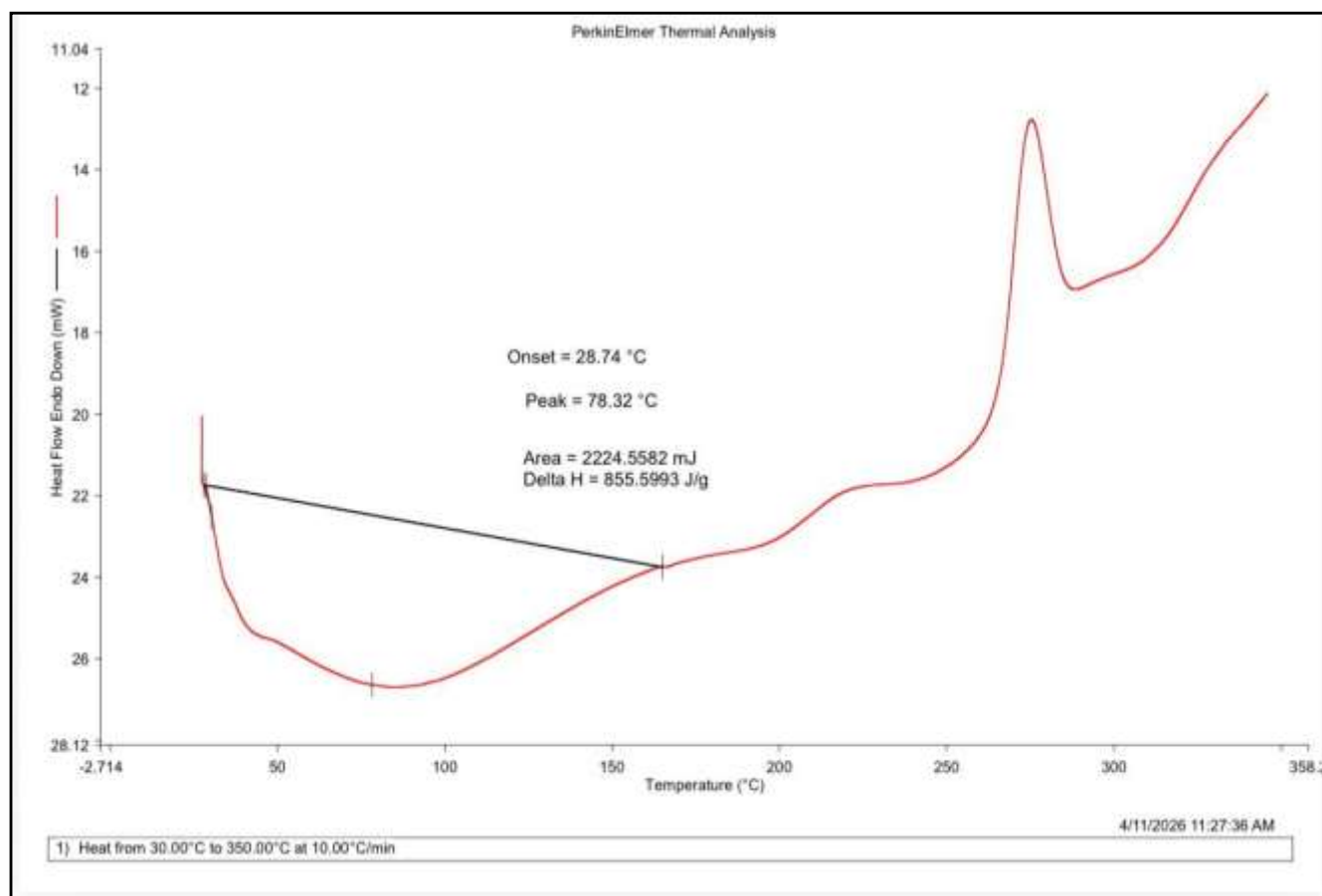
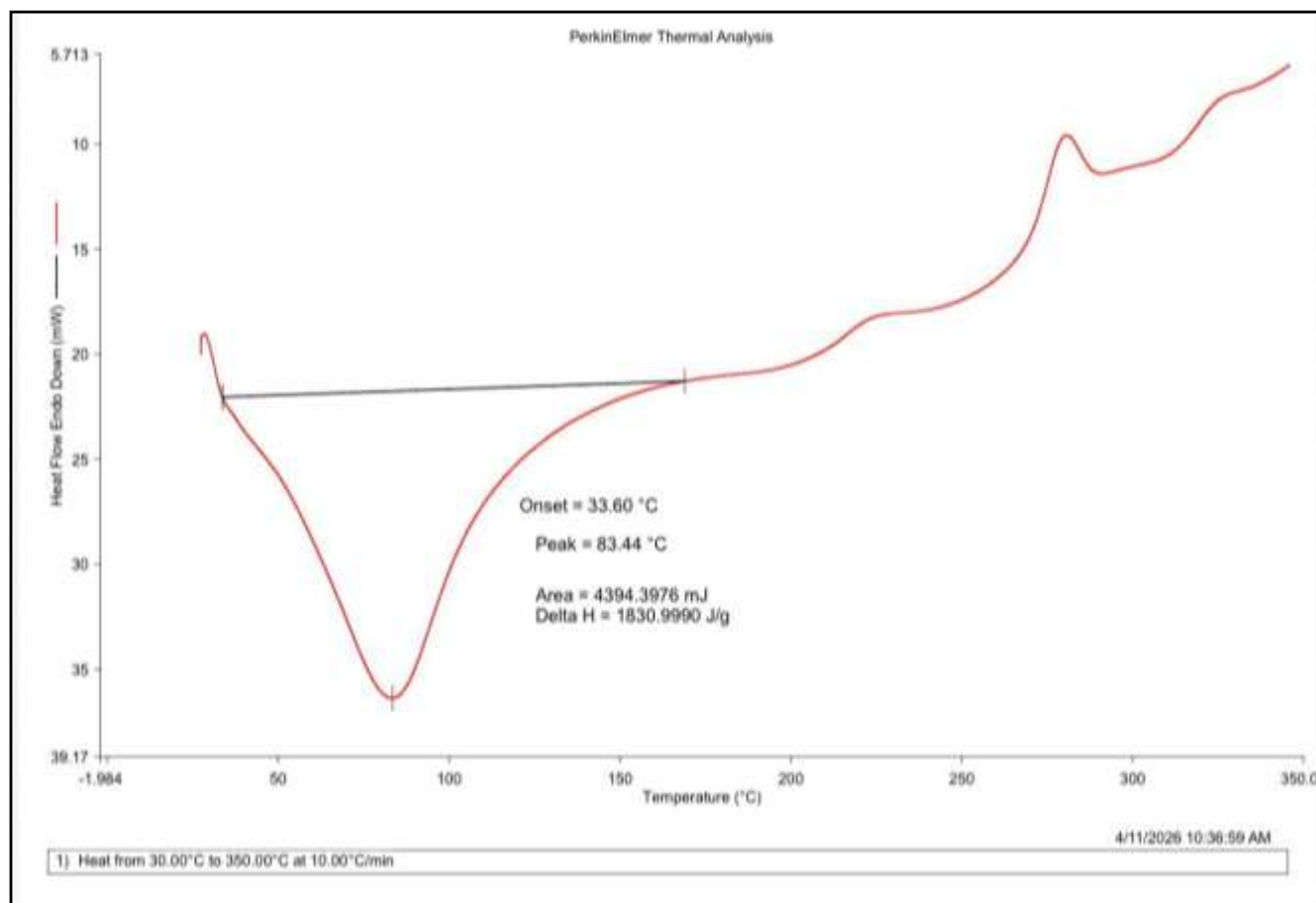
Fig 11: At magnification of ×5000

In comparison to the control sample, the SEM observations verify that the addition of quinoa flour (T_3) considerably changes the microstructure of muffins, resulting in a denser, less porous, and more cohesive matrix.

This is explained by quinoa's distinct makeup, including its increased protein content, lack of gluten, and presence of dietary fiber, all of which have an impact on batter rheology

and gas cell stability.

Overall, the T_3 sample showed a homogeneous and compact microstructure, which could explain variations in textural characteristics like decreased softness and increased stiffness. These results demonstrate how quinoa flour affects the structural and functional characteristics of baked goods.

DSC (Differential Scanning Calorimetry)**Fig 12:** DSC of control sample**Fig 13:** DSC of T₃ sample
~ 550 ~

The produced quinoa flour muffins' differential scanning calorimetry (DSC) thermograms showed significant thermal transitions linked to starch gelatinization and structural alterations during heating. In the temperature range of roughly 70-90 °C, the thermograms showed a distinct endothermic peak, which is indicative of the gelatinization of the starch in the muffin matrix.

The control sample had an enthalpy change (ΔH) of 855.59 J/g, a peak temperature of 78.32 °C, and an onset temperature of 28.74 °C. A less ordered starch structure within the matrix is suggested by this comparatively lower enthalpy value, which also shows reduced crystalline order and a lower energy requirement for gelatinization.

In contrast, the T₃ sample had a peak temperature of 83.44 °C, a higher start temperature of 33.60 °C, and a far larger enthalpy change (ΔH) of 1830.99 J/g. The higher onset and peak temperatures demonstrate superior thermal stability of the starch-protein network, whereas the higher enthalpy value indicates a higher degree of molecular organization and stronger intermolecular interactions within the system. The larger and stronger endothermic peak of the T₃ sample suggests increased water absorption and more even heat distribution during gelatinization. This is explained by the optimized formulation, which likely made it simpler to combine the quinoa flour's constituent parts and resulted in a well-structured matrix.

At temperatures beyond 250 °C, the thermograms also showed secondary transitions that may be related to intricate structural changes or the disintegration of macromolecules. These transitions were more defined, which further confirmed the T₃ sample's higher structural integrity. The

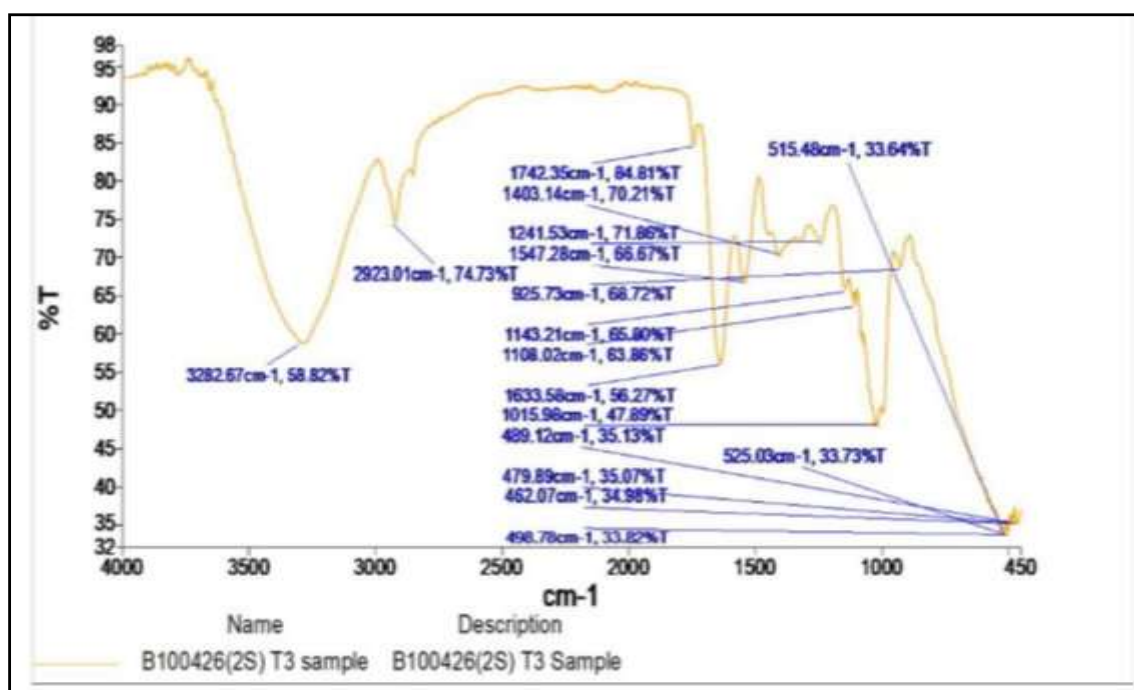
DSC analysis revealed that the T₃ sample generally had superior thermal properties compared to the control. The higher enthalpy and gelatinization temperature indicate better structural organization, increased stability, and enhanced functional performance. Most suitable of the created samples is T₃. These results indicate that the T₃ formulation, which improves the texture, stability, and overall quality of quinoa-based muffins.

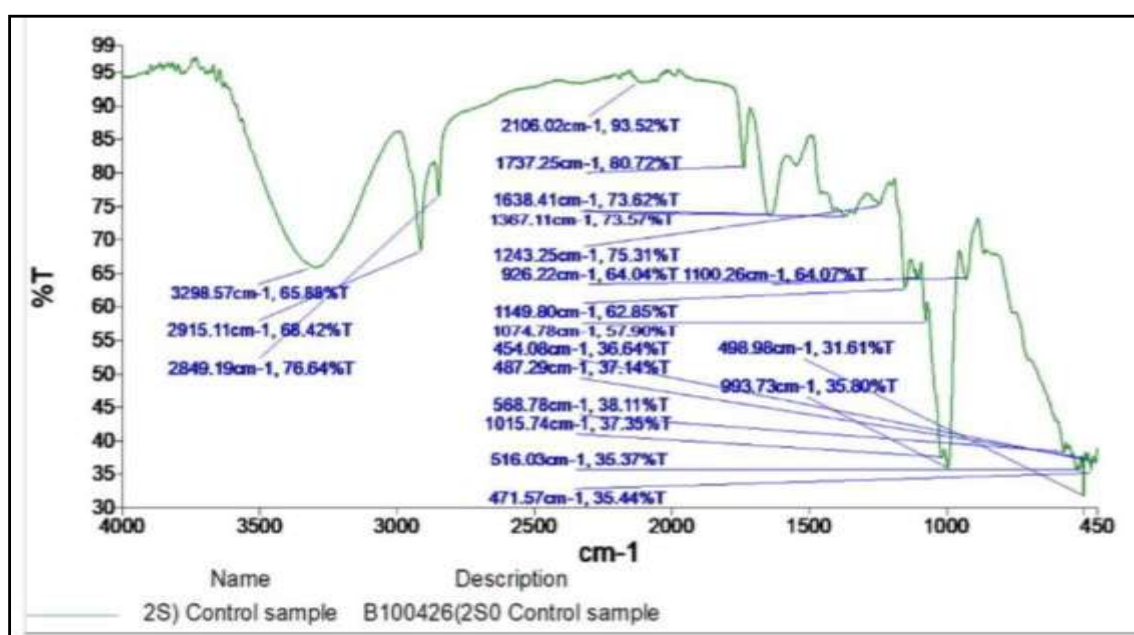
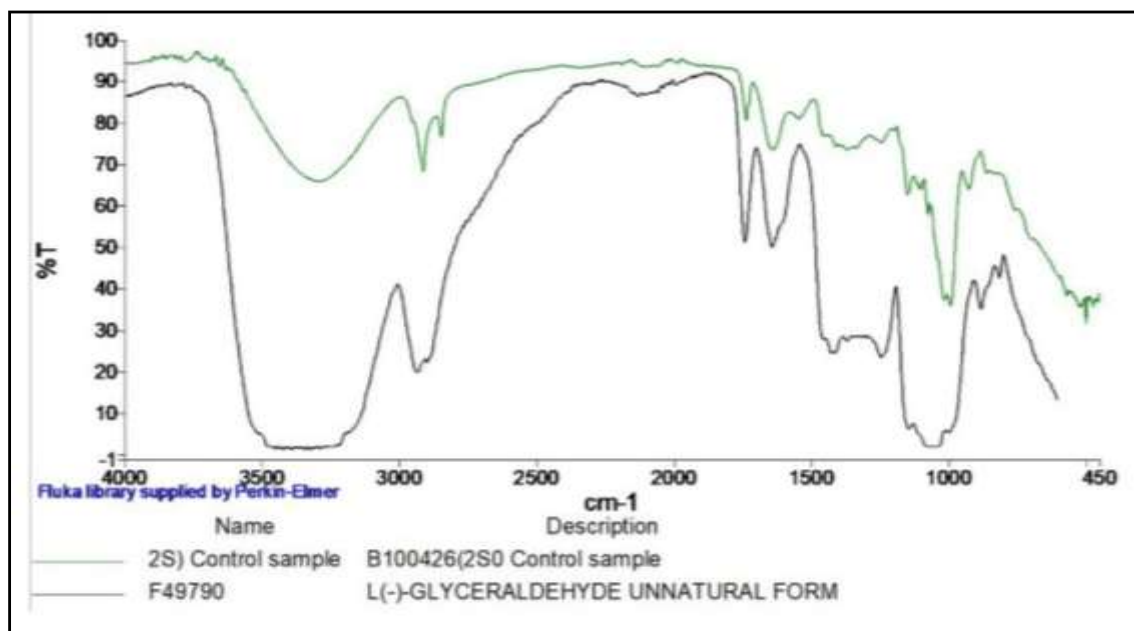
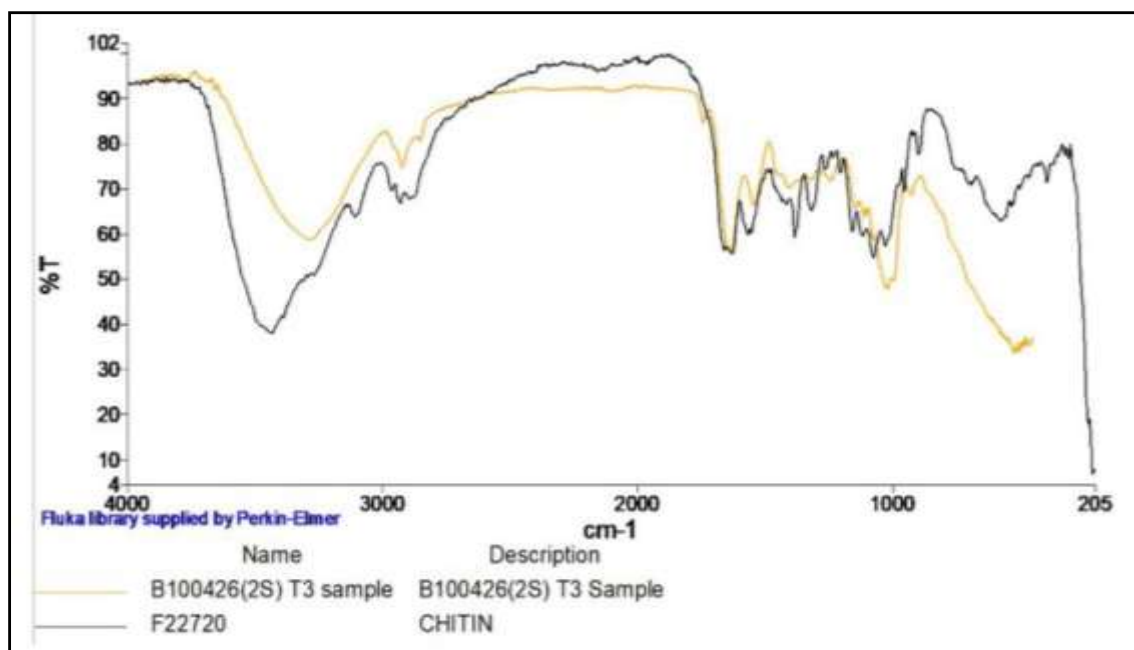
FTIR (Fourier Transform Infrared Spectroscopy)

FTIR spectroscopy was performed to identify the functional groups present in quinoa flour muffins and to compare the structural variations between the control and optimized T₃ samples.

Table 5: FTIR spectra wavelengths and their respective functional groups of muffins developed using quinoa flour

Structural and functional groups	Control	T ₃
O-H stretching (3200-3500 cm ⁻¹)	3298.57	3282.67
C-H (2800-3300 cm ⁻¹)	2915.11 2849.19	2923.01
C = O (1600-1700 cm ⁻¹)	1737.25 1638.41	1633.58
Amide (N-H bending) (1400-1500 cm ⁻¹)	-	1403.14 1547.28
C-O (1000-1300 cm ⁻¹)	1015.74 1074.78 1100.26 1149.80 1243.25	1015.96 1108.02 1143.21





Functional Group Identification

The FTIR spectrum of the T₃ sample exhibited a broad absorption band at ~3282 cm⁻¹, which corresponds to O-H stretching vibrations, indicating the presence of hydroxyl groups from carbohydrates, moisture, and phenolic compounds. This peak was relatively stable and well-defined compared to the control sample (~3298 cm⁻¹), suggesting better hydrogen bonding interactions in T₃.

The peaks observed at ~2923 cm⁻¹ (T₃) and ~2915 cm⁻¹ (control) are attributed to C-H stretching of aliphatic groups, indicating lipid and protein components. The T₃ sample showed slightly sharper intensity, reflecting improved structural integrity.

A prominent peak at ~1742 cm⁻¹ (T₃) and ~1737 cm⁻¹ (control) corresponds to C = O stretching of ester groups, typically associated with lipids. The higher transmittance in T₃ indicates a more stable lipid matrix.

The absorption band around 1633 cm⁻¹ (T₃) and 1638 cm⁻¹ (control) represents amide I (protein) and water bending vibrations. The T₃ sample demonstrated a more defined peak, suggesting improved protein conformation and interaction.

Peaks in the region 1403-1547 cm⁻¹ (T₃) correspond to amide II and CH bending vibrations, confirming the presence of proteins and structural polysaccharides. These peaks were more organized in T₃, indicating enhanced molecular arrangement.

The strong peaks observed in the 1000-1150 cm⁻¹ region (T₃: 1015, 1108, 1143 cm⁻¹; control: 1015, 1074, 1149 cm⁻¹) are attributed to C-O-C and C-O stretching vibrations of carbohydrates. The T₃ sample showed higher intensity and better peak resolution, reflecting improved starch structure and gelatinization.

Additionally, the fingerprint region below 600 cm⁻¹ showed multiple peaks (T₃: 515, 525, 498 cm⁻¹), indicating complex

molecular interactions, which were more consistent in T₃ compared to the control.

Comparative Analysis with Standard Spectra

The T₃ spectrum showed closer similarity to standard compounds such as chitin, indicating structured polysaccharide interactions, while the control sample exhibited resemblance to glyceraldehyde-like structures, suggesting simpler carbohydrate composition.

The overlay spectra further confirmed that the T₃ sample had more aligned and stable peaks, whereas the control sample showed broader and less defined bands, indicating weaker intermolecular interactions.

Interpretation and Significance

The improved peak sharpness, intensity, and reduced band shifting in the T₃ sample indicate:

- Enhanced protein-carbohydrate interactions
- Better starch gelatinization
- Stable lipid integration
- Stronger hydrogen bonding
- These structural improvements suggest that the formulation used in T₃ resulted in better molecular organization and stability.

Based on FTIR analysis, the T₃ sample demonstrated superior structural characteristics. In comparison with the control sample, the presence of well-defined functional groups, stronger intermolecular interactions, and improved spectral stability confirms that T₃ is the optimized formulation for quinoa flour muffins.

Sensory properties of developed muffins

Table 6: Sensory properties of developed muffins

S. No	Variables	Control	T ₁	T ₂	T ₃
1	Colour	8.02 ± 0.72	7.62 ± 0.69	7.54 ± 0.79	8.31 ± 0.12
2	Flavour	8.01 ± 0.60	7.69 ± 0.70	7.90 ± 0.81	8.21 ± 1.10
3	Taste	8.01 ± 0.25	7.81 ± 0.67	7.70 ± 0.91	8.32 ± 1.10
4	Texture	8.24 ± 0.35	7.16 ± 0.15	7.47 ± 0.15	8.10 ± 0.80
5	Overall acceptability	8.30 ± 0.75	8.01 ± 0.71	7.88 ± 0.81	8.21 ± 0.38

The above values are expressed as Mean ± SD (n = 59).

Table 6 displays the generated products' sensory evaluation findings. T₃ received the highest color score (8.31 ± 0.12) among the samples, indicating higher consumer acceptability.

Second place went to the control sample (8.02 ± 0.72). The results for samples T₁ (7.62 ± 0.69) and T₂ (7.54 ± 0.79) were slightly lower but comparable. With a score of 8.21 ± 1.10, T₃ again outperformed the control sample (8.01 ± 0.60) in terms of flavor, suggesting a more pleasing flavor profile. The somewhat lower scores of samples T₁ (7.69 ± 0.70) and T₂ (7.90 ± 0.81) indicate only minor differences in flavor acceptance. Similar trends were seen in taste, with T₃ rating the highest at 8.32 ± 1.10 and the control sample at 8.01 ± 0.25. Sample T₁ came in second (7.70 ± 0.91), and Sample T₂ got the lowest taste score (7.70 ± 0.91). These results suggest that flour treatments had a major effect on flavor development and taste perception.

The control sample had the highest texture score (8.24 ± 0.35), followed closely by T₃ (8.10 ± 0.80), suggesting

similar textural acceptance. Samples T₁ (7.16 ± 0.15) and T₂ (7.47 ± 0.15) had texture ratings that were almost identical but marginally lower. In terms of flavor, texture, and overall sensory appeal, T₃'s score of 8.21 ± 0.38 nearly equaled the control sample's score of 8.30 ± 0.75, which represented the combined influence of all sensory qualities. The findings indicate that, with the exception of the T₃ formulation, where it improved the final product's overall sensory quality, quinoa flour incorporation did not significantly affect sensory qualities across treatments. The results are consistent with earlier studies published by (Hirpara *et al.*, 2020) [19].

Conclusion

The proximate composition of the generated muffins differed significantly between the control sample and the treatments (T₁, T₂, and T₃) that included quinoa flour. T₁ and T₂ showed decreased energy contents of 347.29 ± 8.26 kcal and 353.10 ± 11.20 kcal, respectively, compared to the

control sample's 363.6 ± 6.88 kcal. Compared to the other treatments and the control, T₃ had a larger caloric value. With the control at $57.48 \pm 0.34\%$, T₁ at $59.27 \pm 1.21\%$, T₂ at $60.94 \pm 2.01\%$, and T₃ at $61.17 \pm 0.66\%$, the carbohydrate content varied moderately. T₃ had a considerably greater protein content ($9.83 \pm 0.01\%$) than the control ($7.37 \pm 0.01\%$), T₁ ($7.49 \pm 0.31\%$), and T₂ ($7.41 \pm 0.15\%$). With values of $10.03 \pm 0.23\%$ (control), $10.29 \pm 1.10\%$ T₁, $10.31 \pm 0.12\%$ T₂, and $10.21 \pm 1.02\%$ T₃, the fat content was comparatively stable in all samples. The control had the highest moisture content ($40.09 \pm 0.10\%$), whereas T₁, T₂, and T₃ had lower amounts ($33.31 \pm 0.31\%$, $33.22 \pm 0.12\%$, and $34.04 \pm 0.04\%$, respectively). The control had an ash concentration of $2.14 \pm 0.01\%$, whereas T₁, T₂, and T₃ had ash contents of $2.12 \pm 0.12\%$, $2.21 \pm 0.19\%$, and $2.35 \pm 0.51\%$, respectively. The control group's dietary fiber content was $6.03 \pm 2.01\%$. T₁, T₂, and T₃ displayed $2.12 \pm 0.12\%$, $2.21 \pm 0.19\%$, and $2.35 \pm 0.51\%$, respectively.

The improved formulation had a higher fiber content, with dietary fiber values of $6.03 \pm 2.01\%$ in the control, $5.12 \pm 1.02\%$ in T₁, $5.31 \pm 0.12\%$ in T₂, and $6.03 \pm 2.01\%$ in T₃.

Color analysis showed slight variations between the T₃ and control samples. The control's greater L* value of 28.82 ± 1.12 suggested a lighter look, whereas T₃'s lower value of 26.48 ± 0.12 suggested a darker color. The b* and a* values decreased from 17.20 ± 1.40 to 16.12 ± 1.10 and from 5.11 ± 1.01 control to 4.12 ± 1.12 T₃, respectively. Despite these declines, T₃ displayed a more uniform and attractive hue, which enhanced customer perception of the product.

T₃'s quality qualities have improved, according to texture profile research. Hardness decreased from 90.47 ± 0.82 mJ control to 81.53 ± 11.6 mJ T₃, indicating a softer texture. Cohesiveness increased significantly from 0.08 ± 0.04 to 1.53 ± 0.11 . Adhesiveness declined from 15.83 ± 5.08 mJ to 14.30 ± 0.95 mJ, springiness from 5.45 ± 1.68 to 2.84 ± 0.20 , and resilience from 0.08 ± 0.04 to 0.06 ± 0.06 . Chewiness dropped from 8.07 ± 0.58 to 0.33 ± 0.06 and gumminess from 91.33 ± 3.12 to 9.33 ± 3.06 . Furthermore, fracturability decreased from 943.33 ± 13.12 to 651.67 ± 14.12 , indicating a product that is less brittle and more delicate.

SEM analysis of the control sample revealed a well-developed gluten network with a continuous protein-starch matrix and identifiable air cells, which contribute to softness and elasticity. In contrast, the T₃ sample displayed a denser, more compact, less porous shape with fewer air cells when quinoa proteins and dietary fiber were present but gluten was absent.

Significant molecular variations between the samples were found by FTIR analysis. Stronger hydrogen bonding was seen in the T₃ sample, which displayed a broad O-H stretching peak at ~ 3282 cm⁻¹ as opposed to ~ 3298 cm⁻¹ in the control. C-H stretching was represented by peaks at ~ 2923 cm⁻¹ T₃ and ~ 2915 cm⁻¹ control. Amide I bands were seen at around 1633 cm⁻¹ T₃ and approximately 1638 cm⁻¹ control, whereas C = O stretching peaks were seen at approximately 1742 cm⁻¹ T₃ and approximately 1737 cm⁻¹ control. The existence of proteins and polysaccharides was confirmed by peaks in the range of 1403 - 1547 cm⁻¹, with improved organization in T₃. The intensity and resolution of the carbohydrate-related peaks in T₃ (1015 , 1108 , and 1143 cm⁻¹) were higher than those in the control group (1015 , 1074 , and 1149 cm⁻¹). In T₃, the fingerprint region <600 cm⁻¹ showed several peaks (515 , 525 , 498 cm⁻¹), suggesting

intricate chemical interactions. Stronger protein-carbohydrate interactions, better starch gelatinization, consistent lipid integration, and improved molecular organization were all present in T₃.

According to the results of the sensory evaluation, T₃ had the highest color score (8.31 ± 0.12), followed by the control (8.02 ± 0.72), while T₁ and T₂ had scores of 7.62 ± 0.69 and 7.54 ± 0.79 , respectively. T₃ received a flavor score of 8.21 ± 1.10 , while control, T₁, and T₂ received scores of 8.01 ± 0.60 , 7.69 ± 0.70 , and 7.90 ± 0.81 , respectively. Taste scores showed a similar pattern, with T₁ and T₂ at 7.70 ± 0.91 , T₃ at 8.32 ± 1.10 , and control at 8.01 ± 0.25 . The control had the highest texture score (8.24 ± 0.35), followed closely by T₃ (8.10 ± 0.80), while T₁ and T₂ had lower ratings. The control had the highest overall acceptance (8.30 ± 0.75), closely matched by T₃ (8.21 ± 0.38).

According to shelf-life study, no yeast or mold development was seen in any samples for 30 days when they were frozen at -18 °C and chilled at <5 °C. At zero hours, no development was seen at ambient temperatures of 27 ± 3 °C. T₁, T₂, and T₃ showed no growth after 24 hours, whereas the control showed 7 CFU/g. Microbial counts rose after 48 hours, with the control at 9×10^2 CFU/g, followed by T₃ (4 CFU/g), T₁ (3 CFU/g), and T₂ (2 CFU/g), suggesting improved resistance in treated samples, especially T₂.

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