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Research Article

Rheological Characterization of Chapatti Fortified with Chia and Cantaloupe Seeds Flour

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ABSTRACT

Chia seeds (*Salvia hispanica* L.) are highly nutritious, offering abundant vitamins, minerals, antioxidants, and omega-3 fatty acids. They contain significantly higher levels of micronutrients than wheat flour. Similarly, cantaloupe seeds (*Cucumis melo* L.) are rich in antioxidants and have been shown to extend the shelf life of chapatti. This study developed and analyzed ten formulations to evaluate the effects of incorporating varying proportions of chia seeds (0–10%) and cantaloupe seeds (0–20%) into wheat flour for chapatti production. The findings highlight the potential of using these seeds to create healthier chapatti without compromising quality. The enriched chapatti exhibited better hydration properties and required shorter dough stability times, suggesting improved efficiency for large-scale production. The addition of chia and cantaloupe seeds enhanced sensory attributes, particularly by softening the chapatti texture, which aligns with consumer preferences for softer flatbreads. The study observed a notable increase in water absorption capacity, ranging from 59.36% to 71.56%. Dough development times varied between 1.52 and 4.32 minutes, while stability times decreased from 9.17 to 4.03 minutes. Chapatti hardness was reduced, with texture values decreasing from 8.936 to 6.91, contributing to its improved softness. Among the formulations, treatment T6 (comprising 74% wheat flour, 20% cantaloupe seed flour, and 6% chia seed flour) achieved the highest consumer acceptability. In conclusion, fortifying chapatti with chia and cantaloupe seed flours not only enriches its nutritional content but also enhances its functional and rheological properties, offering a healthier and more appealing alternative for consumers.

Keywords: Chapatti, Chia seeds, Cantaloupe seeds, Dough rheology, Texture properties.

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INTRODUCTION

Chapatti is un-leavened flat bread locally known as "roti". In Pakistan, it serves as a staple food and contributes a major portion of the diet in Asian countries. It is prepared from wheat flour, 94% of the flour is used in the form of chapatti. Chapatti is traditionally made from flour, salt, and water, kneaded using fists, and given to rest for ten to twenty minutes. The dough gets smoother and more elastic after resting. Small pieces of dough are clipped off and shaped into round balls, which are compressed between the palms to form discs, which are then dipped in flour and rolled out into flat discs using a rotating rolling board. The popped dough is then put on a dry pan that has been preheated and cooked from both faces. Chapattis are slightly cooked on the stove and then cooked immediately over a flame in certain parts of the subcontinent, causing them to puff up. The chapatti cooks quickly from the inside due to the hot steam (Hussnain *et al.,* 2022).

Chia is contained in the family *Lamiaceae*. This plant grows annually and is dominant in Mexico. The word chia means 'oily' and comes from 'chain'. Third most growing crop in Mexico. Currently, it is most interested in the USA, Chile, Japan and Canada. In the new millennium, these seeds are known as 'superfood' or 'new gold'. Chia seeds yield 15,000 tons per hectare per year. The seeds are flat, round and measure 1.2-1.5 mm by 2-2.5 mm. They can have a smooth surface with either a white, grey or brown color and have black spots. They occur more often than the whites; the whites tend to be larger in size (Rekowski *et al.,* 2019). These seeds contain a high number of antioxidants such as tocopherols, sterols, and caffeic acid. They also possess the property of providing the body with omega-3 fatty acids that decrease LDL cholesterol and keep the hearts healthy. Besides, chia seeds help in weight loss by reducing visceral fat. Their high fiber content, between 30–40 g/100 g, and nutrition including calcium, potassium, and magnesium improve the nutrition and quality of the food (Harisha et al., 2023).

Cantaloupe belongs to the family Cucurbitaceae and is widely consumed as a food crop. The production has increased from 20 million tons to 31 million tons over 14 million hectares. The peels and seeds of the cantaloupe are wasted. Every year somewhere between 8 and 12 percent (million tons) of seeds and peels are discarded in the whole world. They are used for food additives and enzyme products. These by-products are low in calories and also have pectin, cellulose, hemicellulose, and Lignin. Amongst their potential industrial products include ethanol, prebiotics, enzymes, protein, and glucose (Rolim *et al.,* 2020). This flour made of dried seeds has been used to make cupcakes, chapatti, jellies, and sweets, an important source of dietary fiber, and does support the product's nutritional score. The seed flour was found to improve the softness, expansion volume, and oil or water absorption capacity of the product. Water absorption capacity (5.8 kg/kg) and swelling volume (4.2 m^3/kg) of the product have been studied. The main hurdle is a lack of awareness of using the by-products of cantaloupe in different products (da Cunha *et al.,* 2020).

People are moving towards healthier food today. Chapatti containing flour of other grains and legumes, glycerol monostearate (and other additives such as gluten powder), is incorporated due to increased interest in a healthy diet to improve the nutritional profile and quality attributes (Kumari *et al.,* 2020). In the subcontinent, various simple food fortifications utilizing chia and cantaloupe seeds, are easily accessible. Improvement of bioactive compounds in chapatti was done using two such seeds, namely chia and cantaloupe. Such an application of seeds in dough making improves its texture, flavor, and quality. This research attempt provides a fortified version of chapatti while maintaining the traditional sense with demands for a healthier version of food. This research will improve the quality and acceptability of fortified chapatti from chia and cantaloupe seeds, which have dietary fiber and polyphenols that are rich in health benefits. They can also improve dough rheology, texture, and taste.

MATERIALS AND METHODS

Raw Material

Raw materials were obtained from the Al-Fatah store in Faisalabad. Analytical-grade chemicals and reagents (Merck, Germany) were used.

Raw Material Preparation

Chia and cantaloupe seeds were cleaned and ground into powder form to a fine granular consistency and sifted in a 150 µm mesh sieve to obtain uniform texture. The powder was packed in polythene bags for further analysis.

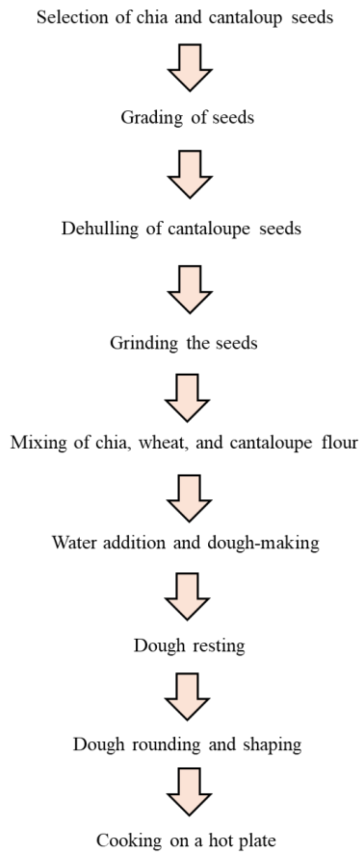
Product Development

The chapatti dough consisted of wheat flour, water, and in addition to that, ground chia seeds and cantaloupe seed flour, rolled into balls and then sealed in a hot pan before serving. Ten preparations were made using RSM software according to Table 1.

Table 1. Preparation of chapatti using various conc. of chia seed and cantaloupe seed.

Treatments	Wheat flour (%)	Cantaloupe seed powder (%)	Chia seed powder (%)
T_0	100	0	0
T_1	90	4	6
T_2	88	8	4
T_3	86	12	2
T_4	82	12	6
T_5	78	12	10
T_6	74	20	6

T_7	84	8	8
T_8	80	16	4
T_9	76	16	8



Flow line of chapatti development

Rheological properties of dough

Chapatti dough was evaluated with farinograph with a bowl containing 50 g under constant flour weight method (Shaabani *et al.,* 2018).

Water Absorption

The water absorption of flour dough is the amount required to reach 500 Brabender Units and to produce a stable dough with a viscoelastic structure (Liu *et al*., 2019).

Dough development time

The time needed to maintain the curve's optimum stability or reach its complete growth high peak values is commonly correlated with longer mixing time (Dangi *et al.,* 2020).

Dough stability time

When the graph's curve remains above the 500 BU line after the first crossing and moves above and below the line, it may be defined as the duration from the time of arrival to the time of departure (Arufe *et al.,* 2019).

Texture analysis

The texture of chapatti was analyzed on a texture analyzer with the help of a 75 mm cylindrical probe. The installed version of the software used to operate the equipment was Texture Expert version 1.22. The samples were compressed for the study of surface structural properties. It measured maximum force, in this case, hardness and distance for fracture strength capability (Walde *et al.,* 2021).

Physical analysis

The digital vernier caliper was used to measure the thickness and diameter of chapatti. Chapatti was placed between the teeth of vernier caliper, and the thickness was measured. Diameter was measured by the measuring scale (Zubair *et al.,* 2017).

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RESULTS

Rheological properties of dough

Water absorption

The amount of water required determines dough stability (Liu et al., 2019). In this experiment, chapatti was prepared using different concentrations of chia and cantaloupe seeds. Samples were analyzed for water absorption, as shown in figure 1. Flour water absorption varied from 59.36 to 71.56%. The values of water absorption in T_0 (59.36%), T_1 (60.92%), T_2 (61.01%), T_3 (63.23%), T_4 (65.15%), T_5 (66.87%), T_6 (71.56%), T_7 (61.87%), T_8 (67.35%), and T_9 (68.31%). Moreover, T_6 has the maximum water absorption (71.56%), followed by T_9 (68.13%). The results with an increase of cantaloupe seed concentration (0–20%) showed that water absorption capacity grew from 59.36 to 71.56%. An increase in chia seed (0–10%) concentration resulted in higher water absorption capacity (59.36 to 66.87%). Chia and cantaloupe seed powders absorbed more water than wheat flour. The results observed that a minimum value (59.36%) occurred in T_0 (control).

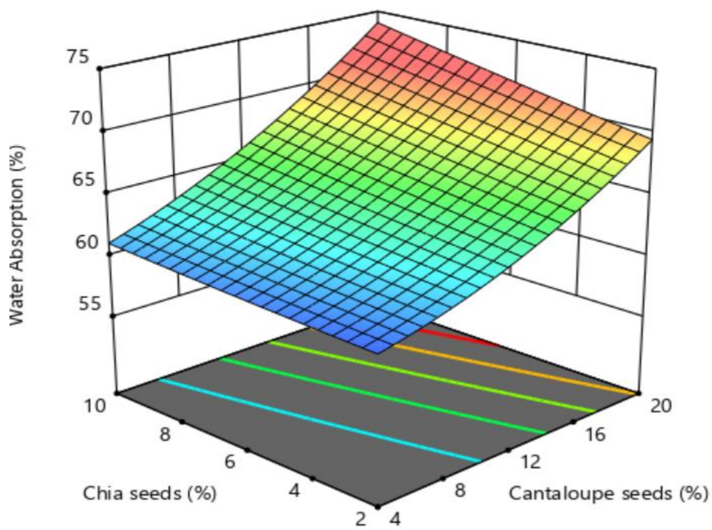

Figure 1. 3D Graphical representation of water absorption capacity of dough influenced by fortification chia and cantaloupe seeds in chapatti.

Gel-like substances are formed when water is mixed with chia seed powder and retains a significant amount of water. Fiber-rich ingredients have a pronounced affinity for water, enabling fiber-based products to retain larger quantities of water. A quadratic model for water absorption was applied to predict through RSM analysis featuring two processing variables i.e. chia and cantaloupe seeds concentrations in chapatti which are expressed below.

$$\text{Water Absorption} = 59.25395 + 0.075669A - 0.037412B + 0.027327AB + 0.019149A^2 + 0.005033B^2$$

This model had a high coefficient of determination (R^2 = 0.9751). It indicates that the model can predict water absorption as a function of chia and cantaloupe contents. The ANOVA results revealed a low P-value (0.0002) which demonstrated the significance of the model equation (Table 2). Thus, statistical evaluation indicated that the model equation can be used to predict precisely the maximum values of water absorption.

Table 2. ANOVA for the effect of treatments on the water absorption capacity of dough.

Source	Sum of Squares	df	Mean Square	F-value	*p-value*
Model	134.46	5	26.89	62.60	0.0002^{*}
A-Cantaloupe	96.26	1	96.26	224.09	0.0001^{*}
B-Chia seed	6.06	1	6.06	14.11	0.0056^{*}
AB	0.5827	1	0.5827	1.36	0.2777^{NS}
A^2	2.55	1	2.55	5.93	0.0409^{*}
B^2	0.0110	1	0.0110	0.0256	0.8768^{NS}
Residual	3.44	8	0.4296		

Lack of Fit	3.44	4	0.8591		
Pure Error	0.0000	4	0.0000		
Cor Total	137.89	13			
R^2	0.9751				
C.V%	1.01				

Dough development time

It refers to the time needed for the curve to reach its peak values, often linked to a longer mixing period or achieving optimal stability for the curve. It marks the interval from the first addition of water to the formation of a stable viscoelastic structure. The samples were analyzed for dough development time, and the results are shown in figure 2. The mean values of dough development time in T_0 (1.52 min), T_1 (1.75 min), T_2 (1.88 min), T_3 (2.01 min), T_4 (2.36 min), T_5 (2.52 min), T_6 (4.32 min), T_7 (1.92 min), T_8 (3.29 min), and T_9 (3.67 min). The results with an increase of cantaloupe seed concentration (0-20%) showed an increase in dough development time of 1.52–3.67 min. In addition, dough development time increased from 1.52 to 2.52 min as the concentration of chia seeds (0-10%) increased. It was observed that T_9 has the maximum amount of time for dough development (3.67 minutes) and T_6, the following (4.32 minutes). Results indicate that treatment (T_0) provided a minimum value (1.52 min). Dough development time increased 1.5 times increase by the addition of chia seeds (0 to 10%) and 2.6 times increase by the addition of cantaloupe (0 to 20%) significantly. Dough development time was 4.3 times increased when using chia and cantaloupe combined versus control. Fiber-rich ingredients have a pronounced affinity for water, enabling fiber-based products to retain larger quantities of water. So, with the increase in water absorption, dough development time also increased.

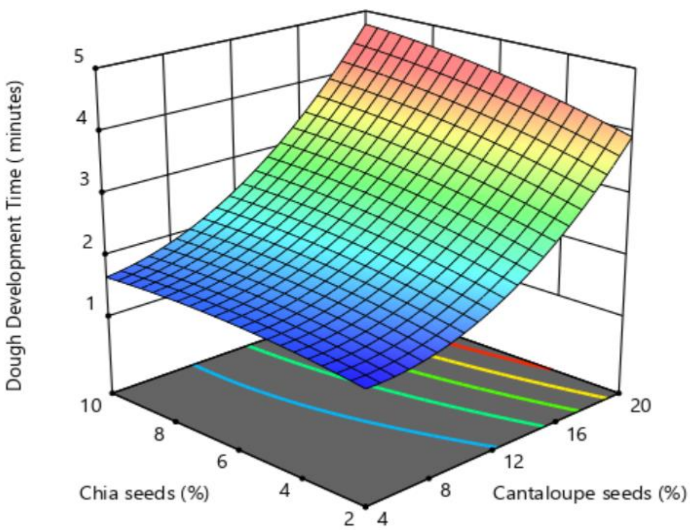

Figure 2. 3D Graphical representation of dough development time influenced by fortification chia and cantaloupe seeds in chapatti.

Moreover, a quadratic model for dough development was applied to predict through RSM analysis featuring two processing variables i.e. chia and cantaloupe seeds concentrations in chapatti which are expressed below.

$$\text{Dough Development Time} = 1.53936 - 0.101721A + 0.088224B + 0.005180AB + 0.010199A^2 - 0.007331B^2$$

This model had a high coefficient of determination ($R^2 = 0.9791$). It indicates that the model can predict the dough development time as a function of chia and cantaloupe contents. The ANOVA results revealed a low P-value (0.0003) which indicated that the model equation was significant (Table 3). Thus, the statistical evaluation indicated that the model equation can be used to predict precisely the maximum values of dough development time.

Table 3. ANOVA for the effect of treatments on the dough development time of chapatti.

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	***p-value***
Model	7.72	5	1.54	74.78	0.0003*
A-Cantaloupe	5.97	1	5.97	289.32	0.0011*

B-Chia seed	0.1918	1	0.1918	9.29	0.0159^{*}
AB	0.0209	1	0.0209	1.01	0.3433^{NS}
A^2	0.7227	1	0.7227	35.02	0.0004^{*}
B^2	0.0233	1	0.0233	1.13	0.3186^{NS}
Residual	0.1651	8	0.0206		
Lack of Fit	0.1651	4	0.0413		
Pure Error	0.0000	4	0.0000		
Cor Total	7.88	13			
R^2	0.9791				
C.V%	5.80				

Dough stability time

The time in which dough maintains its viscoelastic structure is called dough stability time. When the graph reaches the 500 BU line, the dough is stable, when it starts to decline, then it indicates that the dough is starting to lose its stability. This period is also called arrival time to departure time. The samples were analyzed for dough stability time, and the results are shown in figure 3. The stability times ranged from 4.06 to 9.17 minutes. As the concentration of chia and cantaloupe seeds increased, stability time decreased due to the disruption of the gluten network and changes in water absorption. The maximum dough stability time was recorded in T_1 (9.17 min) followed by T_2 (8.97 min). The minimum value (4.03 min) was obtained by a treatment (T_6). The mean values of dough development time in T_0 (8.83 min), T_1 (9.17 min), T_2 (8.97min), T_3 (6.35 min), T_4 (5.76 min), T_5 (5.15 min), T_6 (4.02 min), T_7 (5.65 min), T_8 (4.49 min), and T_9 (4.66 min).

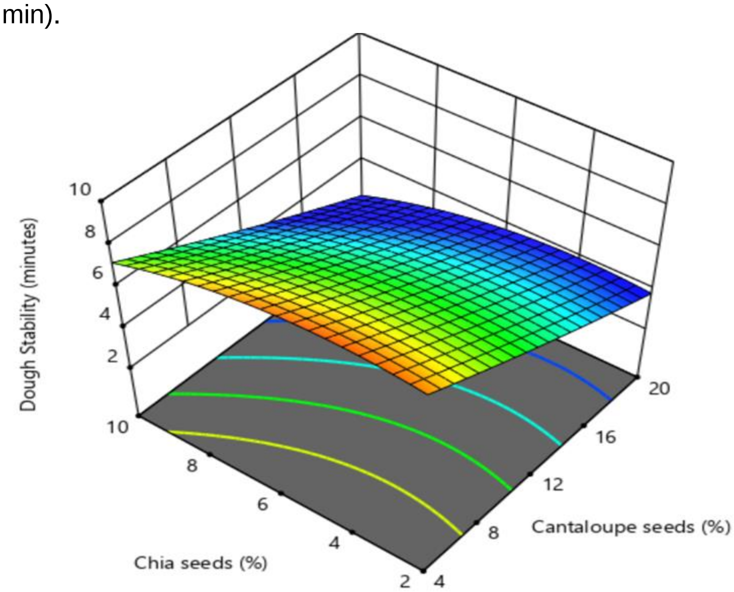

Figure 3. 3D Graphical representation of dough stability time influenced by fortification chia.

Dough stability time increased by 1.6 times and decreased by 2.4 times significantly when the concentration of chia seeds (0 to 10%) and cantaloupe (0 to 20%) increased respectively. Here, dough stability times of the control treatment were decreased 4 times, by chia and cantaloupe seed fortification. The use of RSM analysis for predicting dough development through a quadratic model applied to two processing variables of chia and cantaloupe seed concentrations in chapatti is presented below.

$$\text{Dough Stability Time} = 9.22685 - 0.332944A + 0.396612B - 0.002553AB + 0.001872A^2 - 0.045635B^2$$

This model had a high coefficient of determination ($R^2 = 0.8491$). This means that the model can predict dough development time as a function of variable contents of chia and cantaloupe in the dough mixture. The ANOVA results revealed a low P-value (0.0039) which indicated that the model equation was significant (Table 4). Thus, the statistical evaluation indicated that the model equation can be used to predict precisely the maximum values of dough development time.

Table 4. ANOVA for the effect of treatments on the dough stability time of chapatti.

Source	Sum of Squares	df	Mean Square	F-value	*p-value*
Model	30.38	5	6.08	9.00	0.0039*
A-Cantaloupe	18.12	1	18.12	26.84	0.0008*
B-Chia seed	1.62	1	1.62	2.41	0.1595^{NS}
AB	0.0051	1	0.0051	0.0075	0.9330^{NS}
A^2	0.0244	1	0.0244	0.0361	0.8541^{NS}
B^2	0.9043	1	0.9043	1.34	0.2805^{NS}
Residual	5.40	8	0.6750		
Lack of Fit	5.40	4	1.35		
Pure Error	0.0000	4	0.0000		
Cor Total	35.78	13			
R^2	0.8491				
C.V%	13.36				

Texture analysis

The hardness of the sample was examined using a texture analyzer; the results are shown in figure 4. The maximum force applied by a probe to compress the sample is known as the hardness of chapatti. The area under the curve was used to calculate the hardness value, and the linear distance was used to determine fracturability. A higher peak force indicates a harder sample. Treatment (T0) has recorded the highest value, of 8.88. Whereas treatment (T6), has recorded the lowest observed value that is 5.74, meaning there is a very wide gap between the two treatments. Chia and cantaloupe seeds significantly influenced chapatti texture in Table 5. In addition, there is a small synergistic effect between these two seeds when used together with themselves. This interaction may contribute to improving the overall softness or elasticity of the chapatti. Treatment T_0, with no seed incorporation, exhibited the highest hardness value (8.88), aligning with the traditional texture of chapatti. However, as chia and cantaloupe seeds were added (T_6 with the lowest hardness of 5.74), the texture softened, potentially catering to consumer preferences for softer chapatti.

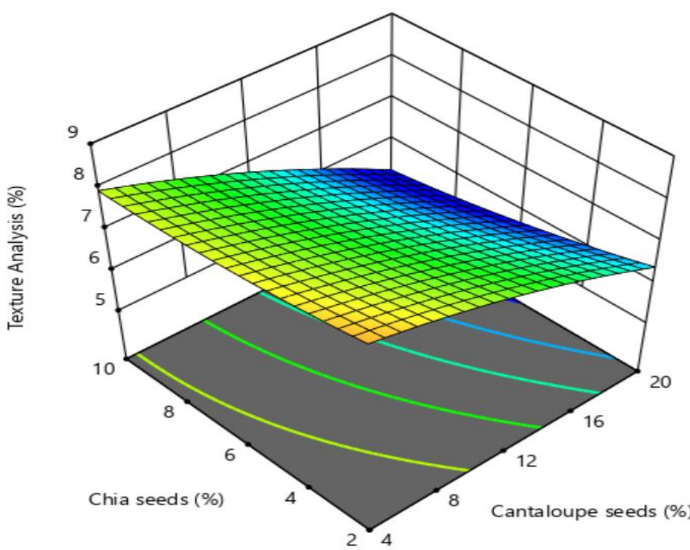

Figure 4. 3D Graphical representation of the texture of chapatti fortified with chia and cantaloupe seeds in chapatti.

Consumer rejection or acceptance of chapatti largely depends on texture, and the reduced hardness observed with seed incorporation could enhance acceptability among those preferring softer flatbreads. This model for the texture was obtained through RSM analysis featuring two processing variables i.e. chia and cantaloupe seeds concentrations in chapatti which are expressed below.

$$\text{Texture} = 8.88431 - 0.038065A - 0.117796B - 0.003713AB - 0.003638A^2 + 0.004824B^2$$

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This model had a high coefficient of determination (R^2 = 0.9838). The ANOVA results revealed a low P-value (0.0003) which indicated that the model equation was significant (Table 5). Thus, the statistical evaluation indicated that this model can be used to predict precisely the maximum values of the texture of chapatti.

Table 5**.** ANOVA for the effect of treatments on texture analysis of chapatti.

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	***p-value***
Model	7.89	5	1.58	97.14	0.0003*
A-Cantaloupe	4.29	1	4.29	264.29	0.0001*
B-Chia seed	0.5371	1	0.5371	33.07	0.0004*
AB	0.0108	1	0.0108	0.6624	0.0493*
A^2	0.0919	1	0.0919	5.66	0.0446*
B^2	0.0101	1	0.0101	0.6223	0.4529^{NS}
Residual	0.1299	8	0.0162		
Lack of Fit	0.0579	4	0.0145	0.8045	0.04809
Pure Error	0.0720	4	0.0180		
Cor Total	8.02	13			
R^2	0.9838				
C.V%	1.77				

Physical analysis

Thickness of chapatti

Physical analysis of chapatti plays an essential role from both the manufacturing and consumer point of view. The samples were analyzed for thickness of chapatti, and the results are shown in figure 5. This study applied chapatti where different concentrations of chia and cantaloupe seeds were added into chapatti. The findings of this study are the reduction of thickness of chapatti due to increased fat content by increasing the concentration of seed. The mean values of thickness in T_0 (2.9 mm), T_1 (2.8 mm), T_2 (2.7 mm), T_3 (2.5 mm), T_4 (2.4 mm), T_5 (2.3 mm), T_6 (1.9 mm), T_7 (2.6 mm), T_8 (2.2 mm), and T_9 (2.1 mm). Maximum thickness was 2.9 mm in the treatment at T0 while minimum was 1.9 mm in treatment at T6. Increase of concentration of chia seed from 0 to 10% decreased the chapatti thickness from 2.9 to 2.3 mm.

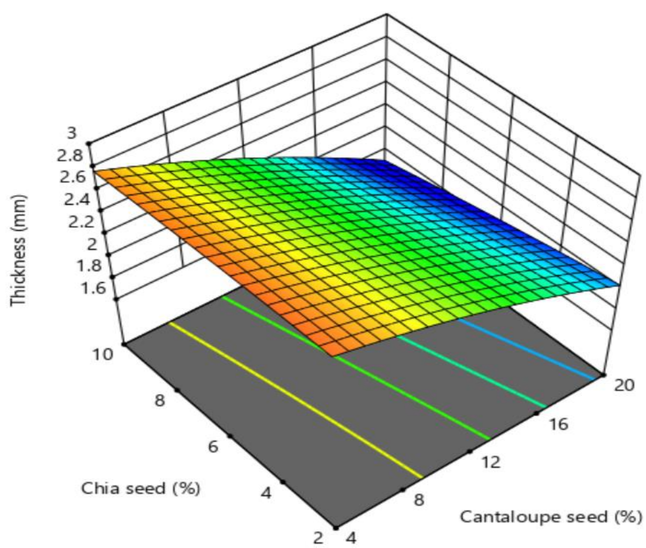

Figure 5. 3D Graphical representation of the thickness of chapatti influenced by fortification chia and cantaloupe seeds.

Similarly, increased concentration of cantaloupe seed from 0 to 20% also showed decrease from 2.9 to 1.9 mm. Results showed that 10% increase concentration of chia seed from 0 to 10% reduced chapatti thickness by 1.6 times and cantaloupe reduced the thickness by 1.2 times from 0 to 20%. In combination reduced the thickness by 1.8 times. RSM analysis was used to obtain a quadratic model for thickness which is given below, containing two processing variables that are chia and cantaloupe seeds concentrations added in chapatti.

$$Thickness = 2.90812-0.02017A+ 0.0138B-0.00225AB-0.0009A^2 -0.0086B^2$$

This model had a high coefficient of determination (R^2 = 0.995). The ANOVA results revealed a low P-value (<0.0001), demonstrating that the model was significant in Table 6. Thus, statistical evaluation indicated that the model equation can be used to predict precisely the maximum values of thickness.

Table 6. ANOVA for the effect of treatments on the thickness of chapatti.

Source	Sum of Squares	df	Mean Square	F-value	*p-value*
Model	0.9245	5	0.1849	361.96	< 0.0001*
A-Cantaloupe	0.6584	1	0.6584	1288.89	< 0.0001*
B-Chia seed	0.0283	1	0.0283	55.43	< 0.0001*
AB	0.0041	1	0.0041	7.97	0.0224*
A^2	0.0069	1	0.0069	13.54	0.0062*
B^2	0.0003	1	0.0003	0.6365	0.4480^{NS}
Residual	0.0041	8	0.0005		
Lack of Fit	0.0041	4	0.0010		
Pure Error	0.0000	4	0.0000		
Cor Total	0.9286	13			
R^2	0.995				
C.V%	0.93				

Diameter of chapatti

Diameter was determined and the findings are summarized in figure 6. Chapatti development was shown to decrease diameter as chia and cantaloupe seeds were added. Based on the results it was concluded that as the concentration of chia and cantaloupe seeds increases, their diameter also decreases because of the increased content of fat. The mean values of diameter in T_0 (20.4 mm), T_1 (19.7 mm), T_2 (19.3 mm), T_3 (18.7 mm), T_4 (18.5 mm), T_5 (18.2 mm), T_6 (17.4 mm), T_7 (19.02 mm), T_8 (17.9 mm), and T_9 (17.6 mm). Among all treatments, the highest diameter (20.4 mm) was observed in treatment (T_0), and the lowest diameter (17.4 mm) in treatment (T6). It was found from an investigation that, with an increase in chia seed concentration (0 to 10%) the diameter of chapatti reduced from (20.4 to 18.2mm). Similarly, as the concentration of cantaloupe seeds increased from 0 to 20%, the thickness of chapatti decreased from 20.4 to 17.4 mm.

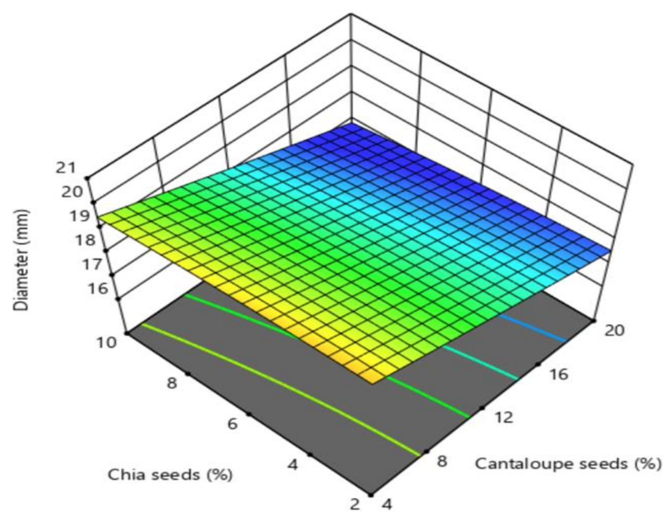

Figure 6. 3D Graphical representation of the diameter of chapatti influenced by fortification chia and cantaloupe seeds.

The diameter of chapatti decreased by 1.4 times as the concentration of chia seed (0–10%) increased and by 1.2 times as the concentration of cantaloupe (0–20%) increased. Chia and cantaloupe seeds together decreased the diameter by 1.5 times. The reason behind the decrease in diameter is less moisture absorption due to an increase in fat content and chapatti starts to shrink due to this property. Increasing fat content in chapatti reduces its ability to absorb moisture, which limits expansion during cooking. This leads to the chapatti shrinking and having a smaller diameter, as the fat prevents the dough from holding enough water for proper expansion.

$$\text{Diameter} = 20.416 - 0.14577\text{A} + 0.02510\text{B} - 0.0029\text{AB} - 0.00042\text{A}^2 - 0.0045\text{B}^2$$

This model had a high coefficient of determination (R^2 = 0.976). The ANOVA results revealed a low P-value (<0.0001) which showed that this model was significant (Table 7). The **Cor Total** is the same as the **total Sum of Squares** but adjusted to reflect the removal of the mean.

Table 7. ANOVA for the effect of treatments on the diameter of chapatti.

Source	Sum of Squares	df	Mean Square	F-value	*p-value*
Model	8.19	5	1.64	244.28	< 0.0001*
A-Cantaloupe	4.64	1	4.64	691.92	< 0.0001*
B-Chia seed	0.2101	1	0.2101	31.34	0.0005*
AB	0.0070	1	0.0070	1.04	0.3372^{NS}
A^2	0.0013	1	0.0013	0.1884	0.6757^{NS}
B^2	0.0090	1	0.0090	1.34	0.2808^{NS}
Residual	0.0536	8	0.0067		
Lack of Fit	0.0536	4	0.0134		
Pure Error	0.0000	4	0.0000		
Cor Total	8.24	13			
R^2	0.976				
C.V%	0.43				

DISCUSSION

The seed powder of chia and cantaloupe greatly influences the rheological properties of chapatti dough. The fiber content in them and the fact that they are able to bind water increase water absorption greatly. Quadratic model for water absorption- R^2 = 0.9751 describes water absorption and thus represents the interaction between the two seed concentrations. Results support findings of earlier research that said the gel-forming ability of fiber-rich constituents enhances water absorption (Hussain et al., 2021).

Seed addition increased dough development time, which is important for stability. Chia and cantaloupe seeds had a 4.3-fold increase in dough development time compared with the control, indicating a major impact on dough structure. This is in line with previous literature that has connected water absorption with dough development time (Pasqualone et al., 2019). The quadratic model confirms the reliability of the finding with a value of 0.9791 (P-value = 0.0003).

Dough stability time was in the reverse trend since a higher concentration of seed reduces stability since it ruptures the gluten network and absorbed more water. The maximum stability was recorded in T0 of the control group while the seed-enriched samples, especially T6 was less stable. The finding was consistent with earlier work that established the fiber additive rich in the additive diminishes the gluten matrix reducing the stability (Arufe et al., 2019).

Addition of seeds significantly changes the texture of chapatti. Hardness, with an increase in the addition of seeds, decreases, and hence T6 is the softest. This softening is in favor as most consumers prefer softer chapatti, and this combination enhances softness and elasticity together. The quadratic model for texture has an R^2 of 0.9838, predicts the changes accurately, and has a significant P-value at 0.0003. Thus, it supports literature suggesting seed incorporation enhances the texture of baked goods (Shaikh et al., 2020).

As size reduced, thickness and diameter of both seeds directly correlated to lower levels of chia and cantaloupe seed content. Higher fat content caused reduced absorption moisture from the seeds, which prevented the dough to expand sufficiently in cooking besides lowering dropped dough thickness by 1.6-fold for both contents of chia, 0 to 10 percent, and by 1.8-fold across both seed types. The diameter was decreased 1.4 times by the addition of chia seeds and 1.5 times by the combined seed addition, which agrees with the trends reported by Hussnain et al. (2022) and Zanib et al. (2018) for baked products.

The R-squared values for the quadratic model's thickness and diameter are 0.995 and 0.976, respectively. This confirms the experimentally obtained results with low P-values, meaning the model is significant. The thinner and smaller diameter dough result from the high seed fat content that prevents the dough from expanding and lower water absorption. Other fiber-rich formulations are in agreement.

CONCLUSION

The study evaluated the effects of fortifying chapatti with chia and cantaloupe seeds using ten treatments with varying seed levels (chia: 0-10%, cantaloupe: 0-20%). The dough rheology, physical characteristics, and texture of the chapatti were analyzed. The study explored the impact of fortifying chapatti with chia and cantaloupe seeds at various levels. The findings showed that chia seeds enhanced water absorption, benefiting the dough's hydration but also extended the dough development time and reduced stability due to disruption of the gluten network. The cantaloupe seeds increased the diameter and thickness because of their positive effects but decreased the texture of chapatti as it was hard. Therefore, fortification of chapatti with chia and cantaloupe seeds may be able to improve the nutritional quality, but it may negatively affect texture, dough handling, and size. Balancing these factors is essential for optimizing chapatti fortification while ensuring desirable sensory and functional properties for consumer acceptance.

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AUTHOR CONTRIBUTIONS

All authors contributed equally to this research.

COMPETING OF INTEREST

The authors declare that the research was carried without any commercial or financial relationships that could be construed as a potential conflict of interest.

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