J. Food. Stab (2026) 9 (1): 28-42 Journal homepage: www.foodstability.com

Received: 22/05/2025 | Revised: 27/09/2025 | Accepted: 02/01/2026 | Available online: 08/02/2026

DOI: 10.36400/J.Food.Stab.9.1.2026-007

Journal of Food Stability

https://www.ajol.info/index.php/jfs

|RESEARCH ARTICLE

Effects of Davis Haden mango kernel flour on bread physical properties and staling kinetics: A comparative study of native and defatted flour

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|Abstract

This study explored the impact of adding Davis Haden mango kernel flour on the physicochemical properties and staling kinetics of wheat bread. Flours made from native and defatted mango kernels were used as substitute of wheat flour, at proportions ranging from 0 to 10%. With an increase in Davis Haden mango kernel flour proportion, there was a corresponding decrease in both baking loss and specific bread volume. The specific volume of the native mango flour remained stable up to proportion 7.5%, but the defatted flour caused immediate decline in specific volume. During the 5-days storage period, there was movement of water from the crumb to the crust. This water migration was more pronounced when there were larger substitution rates, leading to increased water retention in the crumb. The crumb firmness data demonstrated a strong match with the Avrami model (R^2>0.99), indicating the significant contribution of starch retrogradation to the process of staling. The use of native mango flour at a substitution level of up to 7.5% resulted in a reduction in staling rates. Conversely, the use of defatted flour led to an acceleration of staling, most likely due to the removal of lipids and inactivation of enzymes. The acceptable hardness of bread, measured at less than 15N, lasted for 48-98 h for bread made from native flour, and 28-62 h for bread made from defatted flour, depending on substitution rate. Substituting native mango kernel flour at a 5-7.5% in wheat bread increased its shelf-life compared to the control. However, using any amount of defatted flour decreased the shelf-life of the bread. The findings indicate that the utilization of Davis Haden mango kernel flour, especially in its original state, might enhance the quality of bread and mitigate the process of staling when employed as a partial replacement for wheat flour, up to an optimal limit. This study offers valuable insights into the utilization of mango kernel flour to improve the qualities of bread and prolong its shelf life.

Keywords: Davis Haden mango kernel flour | Bread staling | Crumb firmness | Avrami model

1|Introduction

All baked foods go through a series of chemical and physical changes after baking that are known as staling (Cauvain, 1998). During storage, oxidation causes a reduction in the freshness and quality of the product.

The main characteristics of staling include the slow hardening of bread as a result of starch retrogradation, the migration of moisture from the crumb to the crust, and macromolecular interactions that result in chain entanglements.

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Due to its plasticizing impact, investigations by Mandala et al. (2007), Mandala and Sotirakoglou (2005), and Rosell and Gomez (2007) have shown that increasing the water content of bread crumb slows down the staling process. By using low-amylose flours, Baik et al. (2003) were able to successfully prevent bread staling in their investigation. Additionally, by cleaving the osidic bonds in starch, amylases reduce the possibility of starch retrogradation. By doing this, bread's staling process is slowed down (Goesaert et al., 2009; Gray & Bemiller, 2003). Additionally, by acting on starch, the interactions between polyphenols and saturated fatty acid lipids (Smith & Johansson, 2004; Smits et al., 2003; Wu et al., 2009) successfully prevent staling.

Mango kernel flours have the capacity to prevent stalling, as supported by the scientific studies previously discussed. These flours are thought to have this potential because of their high content in phenolic compounds and saturated fatty acids, their low amylose content (<20%), their high-water absorption capacity, and their proven amylase activity (Vihishima et al., 2024 ; Ikechukwu et al., 2024 ; N'Guessan et al., 2023 ; Yee and Mohamad 2021). Thus, using mango almond flour in the place of wheat flour would significantly reduce bread staling. The physical characteristics of bread, particularly its volume and the distribution of water between the inner and outer crusts, are predicted to be significantly impacted by ingredient substitutions. Based on studies done on bread-making with various kinds of flours, this conclusion has been drawn (Axford et al., 1968; Balla et al., 1999; Menon et al., 2014; Vittadini & Vodovotz, 2003). Based on this, this study was carried-out with the aim to investigate the physical characteristics and storage behaviors of breads produced using a blend of wheat and "Davis Haden" mango almond flour.

2 | Materials and methods

2.1 | The sample's origin and processing

The mango variety known as "Davis Haden" (Figure 1) was gathered from two peri-urban orchards in Maroua, the capital of the Far North region of Cameroon. This variety is widely grown and consumed in the savannah zone of northern Cameroon. When the fruits were at their ripest stage, they were picked, their pits and skins removed, and the kernel almonds were meticulously removed with stainless steel blades. The two cotyledons of the shelled almonds were separated and dried in an electric forced-convection dryer for 72 h at 40°C ± 1°C, or until the water content was less than 10%. The dried kernels were then ground into a powder using a Culatti hammer mill (Janke and Kunkel), sieved through a 200 µm mesh screen, and split into two groups: the first was left as raw flour, and the second was defatted using the Soxhlet method (UICPA, 1979). Wheat flour (Pelican Rouge brand), was purchased at the Ngaoundere market from La Pasta S.A.

The wheat and mango kernels flours were manually blended for a minute to form the composite flours. To make sure the mixture was well combined, it was then spun, much like in the winnowing process. The percentages of native and defatted mango kernel flours that were used to substitute wheat flour were 0%, 2.5%, 5%, 7.5%, and 10%.

Baker's yeast (*Saccharomyces cerevisiae*) (Saf-Instant France), culinary salt produced and supplied by "Société Camerounaise de Purification de sel," and tap water from "Société Camerounaise des Eaux (CDE)" were used in the bread production studies.

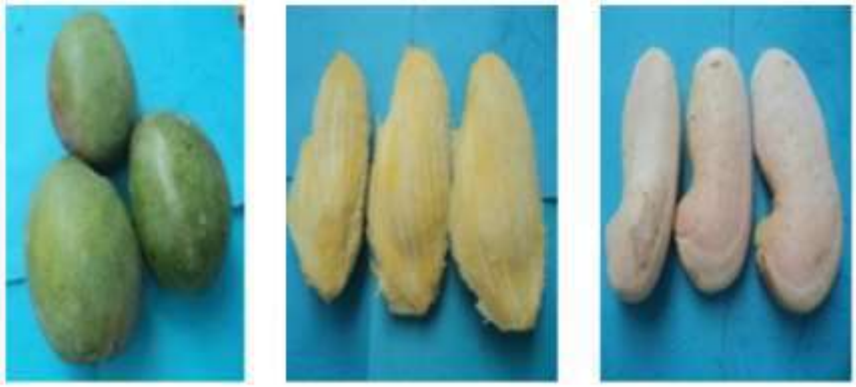

Figure 1: "Davis Haden" mango variety, with pits and kernels used

2.2| Process factor scoping

The French baguette method was selected as the method for producing bread. Because any substitution of wheat with a non-bread flour is likely to cause a change in the dough's behavior due to the composite flour, it was first necessary to frame the process factors through preliminary trials inspired by the literature and with the assistance of professional bakers (Shittu et al., 2007). This required adjusting certain process parameters.

Conditions for kneading

The Severin mixer (Figure 2) has a 1.5 kg dough capacity, 1500 W of rated power, and a discontinuous speed variation (V1 to V12). The kneading element revolves helically in a fixed stainless-steel bowl and is formed like a hook. It is composed of stainless steel.

Figure 2: Severin mixer

Speeds of kneeling

Rotational speeds were measured with a tachometer, since there were no rpm specifications in either the equipment or the manufacturer documentation. For every speed point V, we were able to find the number of rotations that would correspond to that point over the course of a minute. Every measurement was made five times, and the mean plus or minus the standard deviation was used (Table 1).

Table 1: Severin mixer speed indicator

Gear markers (Positions)	Speeds (rpm)
1	18 ± 1
2	31 ± 1
3	43 ± 3
4	58 ± 4
5	71 ± 5
6	84 ± 5
7	95 ± 6
8	110 ± 6
9	132 ± 7
10	156 ± 6
11	175 ± 8
12	196 ± 10

Selecting a speed

Kneading comes in three flavors: enhanced, amplified, and standard. Improved kneading, which is typically utilized in the production of classic French breads, is the method used in this study. It consisted of two steps (Feillet, 2000):

The initial stage of mixing was decided from the preliminary tests to be at a speed of V1 = 43 rpm (mixer position 3) to promote hydration of the ingredients and to maximally use water by flour gluten and starch components. This speed was kept for 5 min both during the autolyse and the first kneading phases. The best mixing speed and time were figured out from the visual control of the dough uniformity.

The second stage, which involved texturizing the dough, was completed in 10 min at a high speed of V2 = 95 rpm (position 7 on the mixer). These values were chosen based on the rheological traits that emerged during this phase, which were evaluated by appearance and touch (smooth, non-sticky dough).

Hydration rate

Water levels in the dough were figured out by first trials where the amount of water was changed in order to get the same dough feel across the wheat flour-mango kernel flour mixtures, as checked by a touch test. A control dough containing 60% hydration (on the basis of wheat flour) was used as the standard for the texture consistency. Table 2 shows the water levels that each wheat-mango kernel flour mixture needed dyeing the reference dough texture.

Factors for fermentation

Yeast concentration was set at 2% (on the basis of flour) referencing literature (Namoune, 1996). The fermentation process took place in a hermetically sealed chamber at 25±2°C and was divided in two stages: (1) bulk fermentation for 30 min (Sahlström & Bråthen, 1997); and (2) final proofing, with the time duration being determined by preliminary dough expansion kinetic tests using a modified method of Havet et al. (2000). For kinetic determination, 100 g dough samples were put into 50 mL graduated cylinders, pressed to the bottom, and covered with light PVC disks that moved upwards as the dough expanded during fermentation. From these experiments, the time for final proofing was decided to be 90 min, which corresponds to the maximum dough volume expansion.

Table 2: Moisture content of wheat - mango almond flour blends

Wheat substitution rate (%)	Hydration rate of composite paste (%)	
	Wheat – Davis Haden's native almond	Wheat – Davis Haden's defatted almond
0.0	60.0	60.0
2.5	61.5	62.0
5.0	63.0	64.0
7.5	64.5	66.0
10.0	66.0	68.0

Conditions for baking

Lecoq (1964) stated that the cooking temperature was set at 220°C. It was possible to determine that 50 min was the right amount of baking time for bread dough based on preliminary experiments conducted at this temperature, which produced a tinted crust similar to that of commercially available loaves.

Bread making protocol used here was a standard one and was optimized for the equipment capacity. Dough pieces of 450 g were mixed, rounded into balls, and subjected to bulk fermentation for 30 min at 25±2°C. After being molded, dough continued final proofing for 90 min under the same conditions. Cooking was done in an electric oven at 220°C for 50 min without steam injection. The bread loaves were taken out of the pans right after baking and cooled 120 min at room temperature to reach hydrothermal equilibrium before being analyzed.

2.3| Physico-chemical analysis of doughs and breads

Baking water loss

The mass loss (M_L) representing the loss on cooking was calculated according to the following formula:

$$M_L(\%) = \frac{dough\ mass - bread\ mass}{dough\ mass} \times 100 \quad (1)$$

The mass of the bread was determined after the proofing time, and the mass of the dough was 450 g, determined as the mass of all the dough pieces.

Loaf volume and specific volume

Loaf volume was measured using the modified AACC (2000) method based on the volumetric displacement of sorghum seeds with a diameter of 3.50±0.50 mm.

A container larger than the loaf is filled with sorghum grains. The measurement itself consists in half-emptying the container of its grain content, then placing the loaf in the container and covering it with the grains previously removed. After levelling the surface of the container with a flat ruler, the excess spherical grains are recovered. Their volume V in cm^3, measured in a graduated cylinder, corresponds to that of the loaf. The specific volume of the bread (V_{sb}), expressed in cm^3/g, is the quotient of the bread volume (V_b) and its mass (M_b) in g.

$$V_{sb}(cm^3/g) = \frac{V_b}{M_b} \quad (2)$$

2.4| Staling kinetics

Moisture content of crumb and crust

Moisture content was determined for the crumb and crust according to the AOAC (1990) method. A thickness of 3 mm from the outside of the loaf was considered as the crust, and the crumb samples were obtained from the central part of the loaf. 5 grams were used in both cases for these analyses, which were carried out at 0, 24, 48, 72, 96 and 120 h respectively, in order to assess the behavior of water between the crumb and the crust during bread conservation.

Compressive strength

The compressive strength of the crumb was measured using an LRFA Brookfield (USA) texturometer (Fig. 3).

Figure 3: Texturometer LRFA Brookfield (USA)

Bread crumb firmness was measured by a texture analyzer with a 35 mm diameter cylindrical probe moving at 1 mm/s, according to AACC method 74-09 (AACC, 1984). Compression tests were carried out at the center of 25 mm-thick bread slices, and peak force at 40% compression was recorded as crumb firmness. This parameter has been shown to have a high correlation with sensory perception of bread softness during chewing and can be used for comparison of different bread samples (Balla et al., 1999). Three radial slices taken from the center of the loaf were used for measurements, and a serrated knife was used for cutting them. The cut surface of the 25 mm thick slices was confirmed with a graduated ruler and straight edge to ensure the surfaces were parallel and uniform before marking the locations for compression tests.

Compression measurements were taken at 0, 24, 48, 72, 96 and 120 h on the slices of bread without remittance. The loaves were stored at room temperature (25±2°C) in low-density plastic bags. The compression force, expressed in Newton (N), is given by the following relationship:

$$F(N) = M \times g \quad (3)$$

With F: value of maximum compression force or hardness (in N); M: the mass of the load allowing this compression (in Kg) as read on the texturometer; g: constant gravity, 9.81 (in N/Kg).

2.4 | Examining mango kernel almond bread's starch retrogradation

The hardening kinetics of bread during storage can be described by the Avrami (1940) model, which is based on crumb starch retrogradation. Equation 4 shows the evolution of crumb hardening over time as an adimensional ratio (FR).

$$FR = \frac{F_\infty - F_t}{F_\infty - F_0} = \exp(-k \times t^n) \quad (4)$$

"n" is the crystal growth index in the crumb during staling, "k" is the constant rate, and F0, Ft, and F∞ are the crumb firmness at zero, t, and infinity, respectively.

In Avrami equation, the value of exponent "n" is close to 1 for starch retrogradation only to be responsible for crumb firming according to Kim and D'Appolonia (1977), while it is greater than 1 for the case of two or more mechanisms. Real equilibrium firmness (at infinite time) was not obtained in this work such a measurement is necessary for the Avrami model to be strictly applied so the crumb firmness was set to 5 days of storage time when it reached 15 N, the threshold of acceptability for bread consumption (Randriamiharison, 1984). This value of firmness was considered the apparent equilibrium state for the model. As a result, the Avrami parameters obtained are apparent staling rate constants (k) and apparent crystallinity development indices (n) rather than the exact kinetic values.

2.5 | Data processing

All measurements were carried out at least in triplicate, and results expressed as mean ± standard deviation. Analysis of variance (ANOVA) of the data was used to assess the influence of variation factors (mango variety, type of flour processing, level of wheat substitution and bread storage time) on responses, and Duncan's test was used to classify significantly different means (p=0.05).

3 | Results and discussion

3.1 | Mango kernel flour's effect on certain bread's physical properties

The main trend shown in Figure 4 (A & B) is that, as the quantity of Davis Haden mango kernel flour increases in the blend, baking loss and specific bread volume tend to decrease. Menon et al. (2014) found similar results after using soy flour and mango kernel flour in place of wheat flour. Results using wheat-soy composite flours and wheat-native soy have been replicated by other writers (Constandache, 2005; Islam et al., 2007; Rodriguez et al., 2006). Because non-bread-making alternative flours dilute gluten, they reduce the dough's capacity to retain CO_2 during fermentation, which may explain why specific bread volume is low. The second group of ingredients also makes it harder for the dough to rise (Dewettinck et al., 2008; Eimam et al., 2008; Elleuch et al., 2011). This keeps the dough from expanding and likely means less volatile compound production during fermentation, which in turn means less crumb honeycombing when baked and less water and volatile matter loss.

causes a significant decrease in the bread's specific volume right from the start.

The distinct impact of the treatment (Davis Haden native or defatted) is likely attributable to the fact that, as previously noted by Brooker (1996), the high specific volume is favored by the substantial amount of saturated fatty acids in the fat of native mango kernel flours. In most cases, the author demonstrates that polar lipids promote the creation of an oil-water layer between the water in the dough and the polar lipids when they are present in the macromolecular network (gluten, starch) that is bread dough.

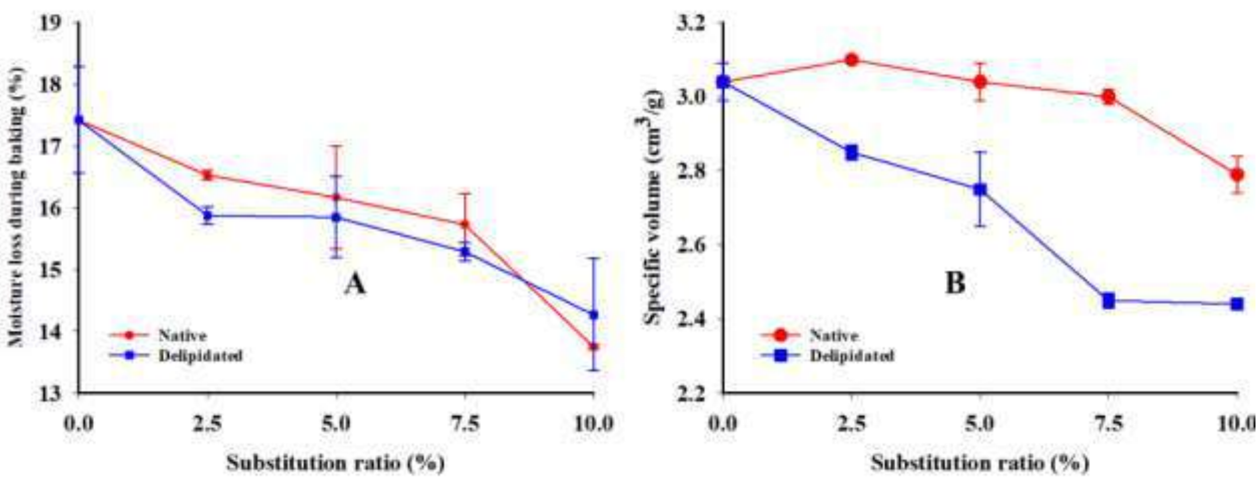

Figure 4: Variations in oven mass loss (A) and specific volume (B) of loaves as a function of substitution rate

Figure 4a demonstrates that there is a slighter reduction in baking loss and a larger increase in specific volume as a result of pre-treatment of almond flour (native or defatted), whereas Figure 4b shows that the magnitude of the decrease in specific volume is higher. In the second scenario, the proportion of Davis Haden native mango kernel flour to total volume remains very constant up to a substitution rate of 7.5% before beginning a downward trend. Conversely, using defatted Davis Haden mango kernel flour as a substitute

Due to adsorption at the water-gas interface, the gas molecules present in the dough-air during kneading and CO_2 during fermentation is trapped by this oil-water double layer. Mango kernel oil contains a lot of saturated fatty acids, which means that when you knead the oil and water together, it forms an interface that looks like a crystal-water interface. This is because saturated fatty acids are crystallized at room temperature, so they adsorb onto the oil-water interface. As the fat crystals melt in the oven, they sink to the gas bubbles' surface and become entangled in the oil-water interface. Gas bubbles expand without rupturing during baking because crystalline material migrates to the bubble interface, thus reinforcing the surface. This results in a higher-volume loaf with a fine crumb structure, and it also helps to reinforce the strength of the oil-water double layer. Davis Haden native mango kernel flour produces breads with a high specific volume, and this process explains why. The specific volume of the bread remains consistent with the control group that did not use Davis Haden mango flour, suggesting that mango kernel fat plays a beneficial effect in this regard (Fig. 4B). The specific volume decreases as the substitution rate for wheat flour exceeds 7.5%, suggesting that this benefit is rate dependent.

The following conclusions can be drawn about the effects of replacing wheat with Davis Haden mango kernel flour on the physical characteristics of bread: The decrease in baking losses, which includes water loss, seems to be economically and staling-wise beneficial. This is because, according to Stauffer (2000), a 2% increase in the crumb's water content extends its shelf-life by one day, so the less water is lost, the longer the bread shelf-life is extended. A up to a 7.5% replacement rate, using Davis Haden native mango kernel flour instead of wheat improves the specific volume, however using defatted flour doesn't seem to work.

3.2| Bread staling behavior as affected by Davis Haden mango kernel flour

Figure 5 shows the behavior of the water content in the crumb and crust after a 5-day period of storage in low-density polyethylene bags at room temperature (25±2°C).

The water content of the crust increases while the water content of the crumb decreases with the storage period, as seen in figure 5. This migration of water from the crumb to the crust occurs during storage. There is a general trend in the water content of both the crust and the crumb towards an asymptotic value, or a likely zone of moisture equilibrium. Crumb dehydration and accelerated staling occur when water diffuses from the crumb to the crust as bread is stored (Le-Bail et al., 2009).

The crust, on the other hand, is unaffected by the rate of replacement (Fig. 5B), but the water content of the crumb rises as the rate of wheat substitution increases (Fig. 5A) for the same storage time. It appears in this particular study that the high water-binding capacity of Davis Haden mango almond flour is most apparent at the crumb level, but does not resist evaporation at the crust level. As a result, the driving force of water diffusion from the crumb to the crust is increased.

According to research conducted by Fik and Suorwka (2002) and Rogers et al. (1988), it has been demonstrated that the staling phenomenon, a tangible indicator of bread hardness during storage, is caused by the evolution of residual water in bread. Stauffer (2000) discovered that a 2% increase in crumb water content extended the shelf life by one day, and Fessas and Schiraldi (1988) demonstrated that, because water acts as a plasticizer in bread, reducing its crumb content encourages the formation of hydrogen bonds between starch-protein polymers, which helps to increase crumb hardness.

3.3| The Davis Haden Mango Kernel Bread: A Model for Crumb Firming

Using R^2 values of 0.99 or higher (Table 3), the experimental crumb-firming data for the loaves acquired in this investigation suited the Avrami model completely (Figure 6).

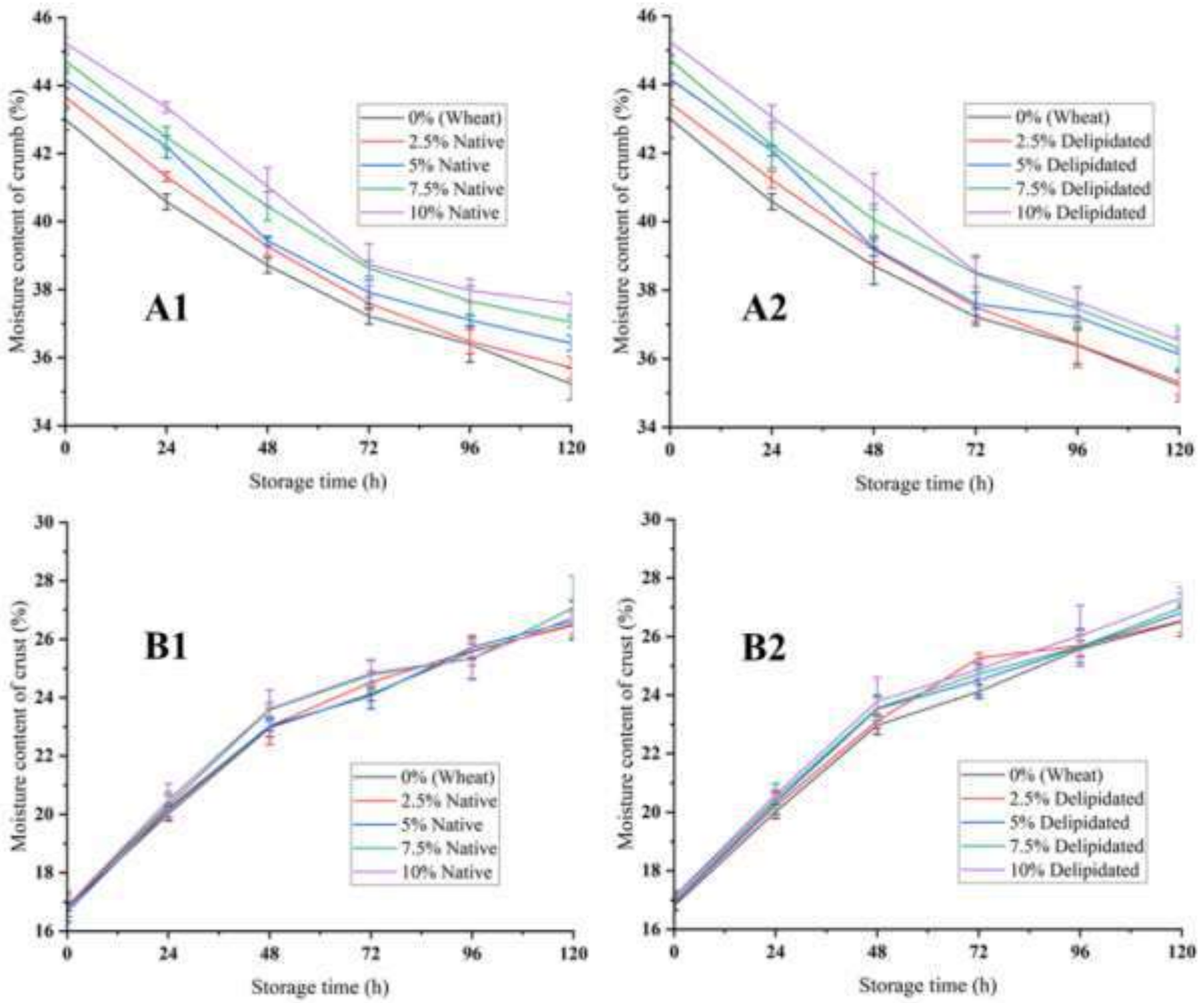

Figure 5: Dynamics of water content in bread crumb (A) and crust (B) during storage time

According to Zobel and Kulp (1996), the crystal development index (n) is larger than 1 for all the loaves. This suggests that starch retrogradation is likely a contributing factor in the staling of the loaves. Study of the firming rate constant (k) and crystal development index (n) after freeze-drying that mango variety (Davis Haden), kernel processing method (native or defatted), and substitution rate have a significant impact on staling kinetics. As the substitution rate for native almond flour for the Davis Haden variety increases from 0% to 7.5%, the letters "n" and "k" decrease, but they grow beyond these thresholds. However, these constants showed a steady rise when defatted flours were substituted. Based on these findings, using local mango almond flour can help decrease bread staling by up to 7.5%.

Conversely, bread staling is more likely to be improved when using Davis Haden mango almond defatted flour (Figure 6B) compared to native Davis Haden mango almond (Figure 6A). It is possible that the inactivation of mango kernel amylases during the delipidation process is responsible for the undesirable effects of the defatted flour.

Table 3: Characteristics of the Avrami model fitted to crumb firmness data for breads made with wheat and Davis Haden mango kernels flour during storage

		K (h^{-n})	n	R^2
Native	0%	$0.7*10^{-3}$	1.4751	0.9995
	2.5%	$0.3*10^{-3}$	1.3743	0.9912
	5%	$0.2*10^{-3}$	1.3783	0.9978
	7.5%	$0.6*10^{-4}$	1.2352	0.9986
	10%	$1.5*10^{-4}$	1.4667	0.9905
Defatted	0%	$0.7*10^{-3}$	1.4751	0.9995
	2.5%	$2.1*10^{-4}$	1.3176	0.9976
	5%	$1.7*10^{-4}$	1.3738	0.9976
	7.5%	$1.20.10^{-3}$	1.5102	0.9940
	10%	$1.30.10^{-4}$	1.7445	0.9976

With k the staling constant rate and n the crystal development index.

Asaduzzaman and Chun (2014) and Ogino et al. (1994) found that enzymes can be rendered inactive by denaturing their protein structures during lipid extraction using hexane. The extraction process, which involves heating the mango kernels at 69°C for 10 h, is also likely to have played a role in the enzymatic inactivation because it exceeded the temperature at which the amylases found in the kernels are most active. Defatted Davis Haden mango kernel flour may have an additional level of explanation for its staling effect. This is because, without lipids, particularly saturated fatty acids, which promote the formation of a lipid-starch complex that can reduce starch retrogradation and, thus, bread crumb hardening, the amylose chains are free to crystallize more easily, leading to increased staling (Knightly, 1988; Krog et al., 1989).

At 7.5% substitution with native mango kernel flour, there seems to be a threshold effect. This could be because, first, the crumb condition gets more compact as the wheat substitution rate increases, leading to a higher compressive strength in the bread. Secondly, the specific volume of the substituted flour is much lower (2.71 cm^3/g) compared to the control (3.04 cm^3/g).

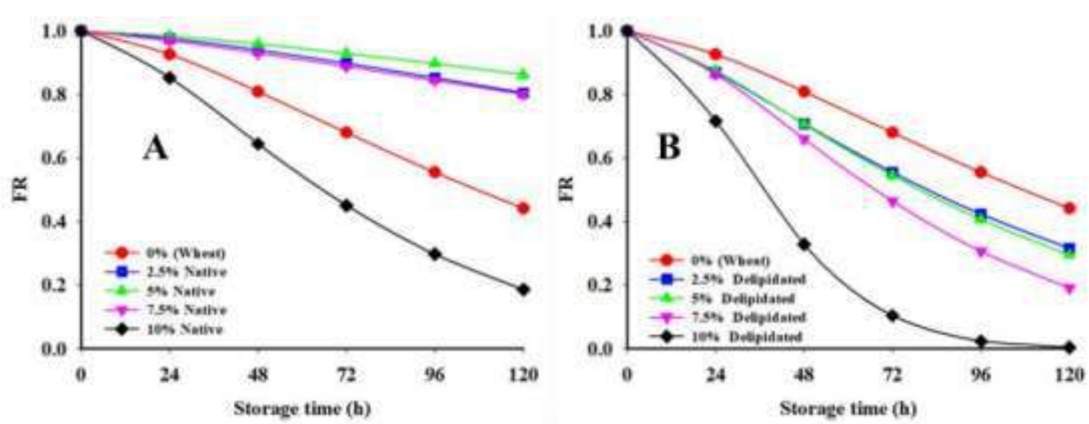

Figure 6: Dimensional adjustment of the effect of wheat substitution by native (A) and defatted (B) Davis Haden mango almond flour as a function of storage time (shelf life) using the Avrami model

It is true that the specific volume of the bread determines the rise in crumb firmness (Axford et al., 1968), but a negative link between crumb firmness and specific volume (Armero & Collar†, 1997) has also been demonstrated.

From the Avrami equation, we obtained F_t, which leads to equation 5, which we used to calculate the consumption duration of the loaves in this study:

$$F_t = F_\infty - (F_\infty - F_0) \quad (5)$$

Figure 7, which is a graphical depiction of the F_t fit, indicates that the firmness of each loaf rises with storage time, which is supported by the data in Table 4. Davis Haden mango kernel flour's pre-treatment (native or defatted) and the rate of wheat flour substitution determine the acceptable range of bread hardness (15N) (Randriamiharison, 1984), which varies from 24 to 72 h.

Breads with up to 7.5% substitution have a hardness similar to the 100% wheat control.

Table 4 : Shelf life of breads made with composite wheat/mango almond flours of the Davis Haden variety

Substitution ratio	Native	Defatted
0%	75 h	75 h
2,5%	78 h	62 h
5%	98 h	57 h
7,5%	74 h	40 h
10%	48 h	28 h

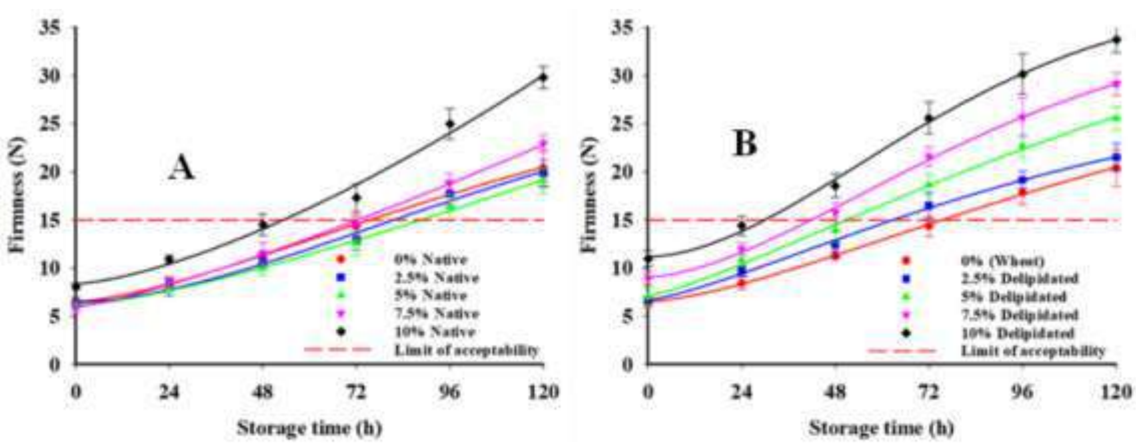

Figure 7: Evolution of the Firmness of bread crumbs (wheat-Davis Haden native mango kernel (A) and wheat-Davis Haden defatted mango kernel (B)) as a function of storage time.

Breads made with native mango kernel flour have an acceptable limit of time at 48 h for 10% substitution, 72 h for 7.5% substitution, and more than 72 h for all other types of breads.

Breads made with defatted flour have an acceptable limit of time at 24, 48, and 72 h for breads with 10, 7.5, and less than 7.5% substitution, respectively. Any amount of substitution tends to make the bread harder than the control.

5| Conclusion

This study demonstrates that Davis Haden mango kernel flour can be successfully incorporated into wheat bread formulations to modify its physical properties and staling behavior. Native mango kernel flour, when substituted for wheat flour up to 7.5%, maintained or improved specific bread volume and reduced staling rates, extending shelf life compared to control wheat bread. Defatted mango kernel flour, however, accelerated staling and reduced shelf-life at all substitution levels. The optimal substitution rate for native mango kernel flour was found to be 5-7.5%, balancing improved water retention and delayed staling with minimal impact on bread volume. These findings provide valuable insights for the baking industry on utilizing mango kernel flour as a functional ingredient. The innovative impact of this research lies in its potential to reduce wheat dependency, valorize mango processing by-products, and develop novel bread formulations with enhanced quality and extended shelf life, contributing to more sustainable and diverse food systems.

|Acknowledgments

Not applicable.

|Conflict of interest

The authors declare that they have no conflict of interest.

|Data availability statement

The data used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

|Fund statement

No financial support was received for this work.

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Cite this paper as: Zomegni, G., Mbougueng, D. P., Desobgo, Z. C. S., & Ndjouenkeu, R. (2025). Effects of Davis Haden mango kernel flour on bread physical properties and staling kinetics: A comparative study of native and defatted flour. *Journal of Food Stability,* 9 (1), 28-42.
DOI: 10.36400/J.Food.Stab.9.1.2026-007

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