

MANGO (*Mangifera indica*) KERNEL STARCH PUDDING : RHEOLOGICAL, TEXTURAL AND SENSORY PROPERTIES

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ABSTRACT

Agro-industrial by-products are widely utilized to make a variety of products, including food ingredients. The fruit of the mango is composed of 35–60% by-products such as peel and seeds, while the kernel accounts for 45–75% of the seed mass. Because mango kernel has a high starch content, it can be utilized directly for pudding formulations without further processing. Mango kernel starch (MKS) was isolated for comparison with corn starch (CS), the starch most commonly used as an ingredient in puddings. The experiment was conducted using a Completely Randomized Design (CRD), with four treatments (0, 50, 75, and 100% MKS substitution), each replicated 3 times depending on the analysis type. Rapid visco analyser, rheometer, texture analyser, and sensory evaluation were used to test the pudding samples. MKS pudding (all substitution levels) had significantly greater peak viscosity (PV) than pudding made with corn starch (CS). Compared to the pudding containing CS, the MKS pudding had a significantly ($p < 0.05$) higher final viscosity and setback. All MKS-pudding showed reduced cohesion and increased gel hardness. As a result, the final gels with higher MKS content required less penetration energy. In terms of cohesion, panellists' overall acceptance, and pudding hardness, samples containing 50 or 75% MKS were preferred in terms of cohesion, hardness, and overall acceptability. Comparing MKS-pudding to a commercial sample, the former performed better. Based on the data collected in this research, ground mango kernel shows promise as a cost-effective and sustainable starch source for pudding formulations.

Keywords: mango kernel starch; pasting; texture; pudding; sensory

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Published first online December 25, 2025

Published final February 28, 2026

INTRODUCTION

Starch is inexpensive, widely available, and extensively used in both the food and non-food industries in addition to providing nourishment for humans and animals. The morphologies, structures, and properties of starches derived from diverse plant sources vary, thereby influencing their respective applications. The structural and functional characteristics of starches from commercially important sources, including cereals, tubers, and legumes, have been extensively studied. However, as food and non-food sectors expand, there is growing interest in identifying novel starch sources with unique functional properties. Starch occurs in two structural forms: branched chains (amylopectin) and linear chains (amylose). These two polysaccharides make up all starches; the ratio of amylose to amylopectin varies depending on the starch source, typically around 30:70. Additionally, the distribution of granule size, the distribution of amylopectin chain length, and the crystalline structure of starches from different sources show differences in how they are organized. The crystalline portions of amylopectin will melt if they are

heated in an abundance of water, which results in the granules becoming swollen, a process that is referred to as gelatinization.

When it comes to the culinary sector, corn starch is frequently used as a thickening ingredient in a variety of desserts and puddings. Puddings and custards frequently incorporate starch as an ingredient, generally alongside additional components like sugar and milk (Matser & Steeneken, 1997). Many well-known dishes are made with milk that has been thickened with starch. The usual amount of corn starch to milk for making corn starch pudding is 2 grams of starch and 4 grams of sugar per 240 milliliters of milk (Lim & Narsimhan, 2006). So, the normal amount of cook-up starches used as thickeners in dairy products is 1–6% (w/w), and this depends on how thick you want the final product to be. You can utilize common sugars like sucrose, glucose, and fructose to make treats like puddings.

Typically, starches are cooked to bring out the flavour and maximize their thickening potential. Cooking enhances the nutritional value of other starches, such as potato starch, and maize starch as an energy source. Controlling the rheological characteristics of starch-

containing foods requires understanding the effects of temperature and shear rate, as well as their combined influence during processing. Thus, the gel rheology varies depending on whether starch is cooked directly or using a heat exchanger (Lagarrigue & Alvarez, 2001).

The flow behavior of starch gels depends on the type and concentration of gums. When corn starch and okra gum were combined, the RVA data revealed that samples with more okra gum had higher peak viscosity, less breakdown, and more setback. On the other hand, a lower flow behavior index (n) indicates stronger pseudoplasticity in pudding systems (Abdo Qasem *et al.*, 2017). Sugars can enter the starch granule during the swelling stage of starch gelatinization and combine with amylose and amylopectin to raise the gelatinization temperature. Sugars disrupt the amorphous regions of starch granules, increasing gelatinization temperature, as shown in starch–sugar systems. The results of the starch gel hardness and springiness measurements showed that low molecular weight sugars could slow down the retrogradation of starch. Amylose leaching, delayed starch swelling, and generally limited starch gelatinization were the results of this. Researchers found that the concentration of sugars in the system's continuous phase accounts for the action of sugars (Chiotelli *et al.*, 2000; Sikora & Pielichowski, 1999). According to Evageliou *et al.* (2000), the addition of sugars significantly slowed down the pace of amylose network formation during cooling. This was supported by the observed decrease in G' .

Mango seed is produced in large quantities during the manufacturing of mango nectar, making it an inexpensive and easily accessible raw material for starch extraction and fibre. Utilizing mango seed as an alternative starch and fiber source also offers environmental benefits. Mango kernels are thought to be a major by-product of the fruit processing industry. Researchers suggested using these to address the issues of environmental pollution and the sector's economic viability. The primary component of the mango kernel is starch, which is used in a variety of ways in both the food and non-food industries (paper, textiles, and cosmetics) due to its unconventional nature. Starch is primarily derived from conventional sources (potato, rice, maize, and mung beans) and is predominantly used in human food systems. Furthermore, the advantageous functional characteristics of both native and modified mango starch render it a promising supply of starch for an array of applications. Mature mango seed starch presented oval to disk structure with granule size of 10–13 μm and amylose content of 21–33% (Ferreira *et al.*, 2019). A proximate analysis of the overall composition of different mango cultivars revealed that 55–74% of them were polysaccharides, of which 60% were starch, 9–13% fat, 6–9% proteins, and 2–2% were ash (Mutua *et al.*, 2017). X-ray diffraction (XRD) pattern exhibited A-type starch

(similar to cereal starches) have been reported for some varieties where others exhibited C-type (similar to legume starches) (Thory & Sandhu, 2017). Unripe mango kernel starch showed gelatinization properties comparable to maize starch, but with reduced amylopectin retrogradation. Despite their widely varied sizes and morphologies, mango seeds are, on average, composed of 50% starch and 25% amylose (Guo *et al.*, 2018). Mango starch exhibited a much lower pasting viscosity than rice and maize starches, with certain acceptances (Huang *et al.*, 2015); on the other hand, the pasting viscosities of specific varieties, such as, litchi and jackfruit starches were significantly greater. A promising strategy for utilizing these by-products involves the development of various value-added food products, including bakery items, meat products, and dairy-based offerings.

To the best of our knowledge, no studies have been conducted on the rheological properties of mango-starch or mango-kernel in the presence of high sugar content and milk. Since the amount of starch in the kernel is high, for economical and nutritional reasons, the present study utilized the isolated starch for pudding preparation. Thus, this study aims to investigate the rheological properties, pasting characteristics and texture of the puddings prepared from the formulations containing various levels of mango kernel starch.

MATERIALS AND METHODS

Materials: Mango seed was separated from mango fruits of the Keitt variety purchased from the local market. The experimental work was carried out from September to November 2024. Low fat powdered milk and sugar were purchased from a local market. Corn starch was donated by the Middle East Food Solutions Company (Al Kharj industrial area, Riyadh, Saudi Arabia). Mango kernel was separated from the seed and isolated starch was used for pudding preparation.

Mango Starch Isolation: While the entire mango kernel was used unaltered to prepare the pudding formulation (kernel meal), mango starch has been isolated from the kernel and used specifically to characterize its pasting properties. After removal from its shell, whole seeds were washed and freeze-dried to 4% moisture content, ground and passed through a 500 μm sieve. The dry whole kernel was suspended in distilled water (1:9 W/W) and gently mixed for 15 min using magnetic stirrer. The slurry was centrifuged (3000xg for 30 min, 10°C). The top brownish layer was removed and the pellet was resuspended in distilled water and centrifuged. This process was repeated four times and the white pellet was air dried using acetone. Total starch was determined using the standard method of (AOAC, 2007). Amylose content was determined according to Williams (1970).

Pudding Recipe: The ingredients listed in Table (1) were used for preparing the pudding. 13% of the formulation consisted of either ground MKS or corn starch (control).

The experiment was conducted using a Completely Randomized Design (CRD), with four treatments (0, 50, 75, and 100% MKS substitution).

Table (1). Mango kernel starch (MKS) pudding formulation

Ingredients	0%MKS	50%MKS	75%MKS	100%MKS
Mango kernel starch (MKS)g	0	5	7.5	10
Milk(g)	18.4	18.4	18.4	18.4
Sugar(g)	45	45	45	45
Starch(g)	10	5	2.5	0
Salt(g)	0.4	0.4	0.4	0.4
Flavor(g)	4.63	4.63	4.63	4.63
Oil (mL)	4.61	4.61	4.61	4.61
Water(mL)	135.43	135.43	135.43	135.43

Sample with 0% = 100 corn starch; 100% = Mango kernel starch

Rapid Visco-analyzer (RVA): The ingredients were thoroughly blended, and a 28 mL portion of the mixture was transferred into an RVA aluminum canister for the assessment of the paste viscosity in a pudding formulation (RVA, Newport Scientific Inc., Australia). The samples underwent immediate heating to 50°C for 50 seconds, followed by a gradual increase to 95°C over 4.42 minutes at 12.16°C/min, maintaining this temperature for 5 minutes with a shearing paddle speed of 160 rpm. Subsequently, the mixture was cooled to 30°C for 5 minutes at a 11.84°C/min, completing the test in 20 min. The resulting paste was then used for evaluating the rheological properties and texture of the pudding.

Rheological Measurements: Blends were prepared in RVA under identical experimental conditions as outlined in section 2.4. Cooked gels were carefully transferred to a plate, and the geometric spacing was adjusted to 100 μm . Excess sample material was carefully removed using a spatula. The gels were used for both steady shear test and the viscoelastic test. The dynamic rheological testing was done using DHR Hybrid Rheometer (TA Instruments, New Castile, PA). To ensure that all measurements were made within the linear viscoelastic range (LVR), a strain-sweep experiment was conducted to determine the LVR's range. By increasing the strain from 0.1 to 50.0% at a steady frequency of 0.1 Hz (0.628 rad/s), the LVR test was determined. The linear viscoelastic region (LVR) was reached by constant strain (5%) and the dynamic characteristics were measured at 60°C in the range of 0.1-100 (rad/s) angular frequencies. As a result, the frequency sweep was adjusted to range from 0.1 to 100 (rad/s) while maintaining a 5.0% strain at 25 °C. This suggests that the applied shear strains have no effect on the observed values. Fresh samples were used for each test, and measurements were repeated at least twice, with relative errors within $\pm 10\%$. The TA instrument provided

Rheology Advantage Data Analysis software (Version 5.7.0), which was utilized for data analysis. For the majority of biomaterials, the frequency range of 0.1 to 100 (rad/s) is often utilized to calculate G' , G'' , and η^* . The storage modulus (G') represents the energy stored and recovered each cycle, while the loss modulus (G'') represents energy dissipated. $\tan \delta$ defines the ratio of energy stored to lost energy for each cycle.

The cooked starch gels' steady shear behaviors (shear rate vs. shear stress) and temperature dependency (30, 40, and 50 °C) were noted at varying shear rates of 1 to 100/s. Equation (1) was used to fit the data to the power law model.

$$\tau = k\gamma^n \quad (1)$$

where, τ = shear stress (10 dyn/cm²), K = consistency coefficient (Pa sⁿ), γ = shear rate (s⁻¹), and n = flow behavior index (dimensionless).

Equations (2) illustrate how the data were collected and fitted to the Herschel–Bulkley equations to define the differences in the rheological characteristics of samples under steady shear.

$$\tau = \tau_0 + k\gamma^n \quad (2)$$

Where τ is the shear stress (Pa), γ is the shear rate (s⁻¹), K is the consistency index (Pa. sⁿ), n is flow behavior index (dimensionless) and τ_0 is yield stress.

The influence of temperature (30, 40, and 50 °C) on the flow consistency index at a shear rate of 100 s⁻¹ for the starch gel was investigated and the temperature dependency was determined using the Arrhenius Equation (Equation 3)

$$\ln \mu = \ln A - \frac{E_a}{R} \frac{1}{T} \quad (3)$$

In this context, μ represents the apparent viscosity (Pa s) at a shear rate of 100 s⁻¹ at the specified measurement temperature (Pa sⁿ). A denotes the pre-exponential factor (Pa sⁿ), E_a signifies the activation energy (J/mol), R is the universal gas constant (8.314 J mol⁻¹ K⁻¹), and T indicates the absolute temperature (Kelvins). The E_a value for each treatment was derived from the regression analysis of $\ln \mu$ versus $1/T$ graph.

Pudding texture: After being prepared in the RVA, the pudding gels were transferred in a 25 mL beaker and kept refrigerated (4°C) overnight. Before being assessed for their textural properties, pudding samples were allowed to take room temperature. Using a TA-TXT texture analyzer with 5 mm cylindrical probe (Texture Technologies Corporation, Vienna Court, Lammass Road, UK) at a speed of 0.5 mm/s and a distance of 10 mm in two penetration cycles, the pudding gels were compressed to a maximum penetration force (g). Hardness, cohesiveness, and gumminess are among the measured gel properties that were computed using the method of (Sandhu & Singh, 2007).

Sensory evaluation: Ten trained panelists assessed the four pudding samples in comparison to a commercial sample. Panelists were required to evaluate each sample based on color, exterior thickness, oral thickness, melting, smoothness, flavor, and overall acceptability, on a 5-point hedonic scale ranging from 1 = “dislike very much” to 5 = “like very much.”

Statistical Analysis: All measurements were conducted in three replicates. Data were analyzed employing the one-way analysis of variance (ANOVA) technique. Before applying ANOVA, the data were checked to make sure they were suitable for this test. A normality test and a variance homogeneity test were performed, and the results showed that the data were normally distributed

and had equal variances ($p > 0.05$). Therefore, ANOVA was considered appropriate for analyzing the results. This analysis enabled us to identify the significance of the impact of MKS levels on pudding quality. Duncan’s Multiple Range (DMR) test at $p \leq 0.05$ was employed to compare means using SPSS (PASW® Statistics 18) software.

RESULTS AND DISCUSSION

Rapid Visco-analyzer (RVA): The profiles, in Figure 1, illustrate the differences in pasting properties between corn starch (CS), mango kernel starch (MKS) and the whole mango kernel (MK). At the same solid content, the profile revealed a greater peak viscosity (PV) for corn starch followed by MKS then MK. Relative to the CS (PV= 2872 cP), the PV of MKS and MK were 34% and 65% lower than CS, respectively. From the slope of the RVA line, MKS and MK appeared to exhibit faster swelling power indicating faster water penetration into the granule. Even though there was not a significant difference in the pasting temperature of the two starches, the MKS swelling rate was greater than the CS, resulting in faster gelatinization and a lower PV. This suggests that MKS granules are less compact and have a consistent size (looser structure) that allowed the granules to swell at the same time.

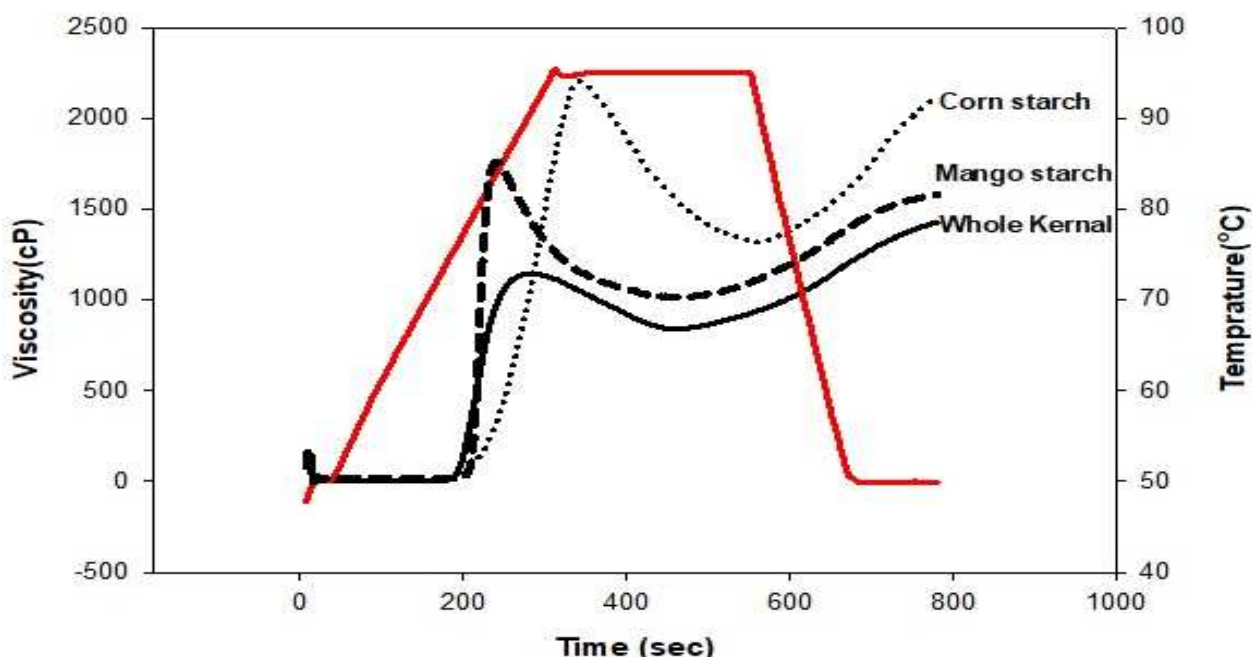


Fig. 1. RVA profile of mango kernel starch, mango kernel seed and corn starches.

Breakdown peak (BD), the viscosity drop from peak to final viscosity, indicates starch stability and granular structure. It can be applied to distinguish between various starches. In addition, the presence of

specific compounds, like sugars or lipids, might influence the breakdown peak viscosity. Breakdown values were 745 cP for MKS and 179 cP for MK, compared to 1081 cP for CS. This suggests that MKS is far more stable than

CS, especially when it manifests as MK. The final viscosity of CS starch is obviously much higher than that of MKS or MK. This will explain the lower hardness of the pudding prepared from MK as it will be discussed later. Setback viscosity reflects the degree of retrogradation, indicated by the viscosity increase during cooling. With respect to the setback (SB) of CS exhibited about 43% higher SB than MKS and 51% more than MK, indicating stronger amylose network after cooling, keep in mind this SB is at 50 °C, because this is not reflective of the final texture of the pudding at room temperature.

When the pudding ingredients were present, both the CS and MKS characteristics changed (Table 2). The blends were made with 100% MKS, 50%MKS, 75%MKS, and 0%MKS (100% CS). Despite CS's substantially higher PV than MKS's, the blends containing MKS demonstrated a significantly ($p < 0.05$) higher PV; this was especially true for the sample that contained 100% MKS according to the ranking MKS>75%MKS>50%MKS>0%MKS.

Table (2). Effect of replacing corn starch with MKS on pasting properties

%MKS	Peak viscosity (cP) ¹	Breakdown (cP)	Final viscosity (cP)	Setback (cP)	Pasting Temp (°C)
0 ²	905.00±0.81 ^d	83.33±0.04 ^d	2018.00±0.01 ^d	1196.33±0.59 ^d	89.83±0.11 ^a
50	1134.78±0.12 ^c	173.70±0.19 ^c	2217.11±0.29 ^c	1256.04±0.45 ^c	89.07±0.05 ^a
75	1382.98±0.32 ^b	414.41±0.41 ^b	2335.23±0.17 ^b	1366.67±0.76 ^b	88.27±0.01 ^b
100	1559.44±0.25 ^a	554.49±0.16 ^a	2438.14±0.05 ^a	1433.19±0.52 ^a	88.59±0.07 ^b

¹Centipoise; ²100% corn starch; Mean carrying same letters in columns for particular MKS content under specific parameter are non-significantly different from each other.

A comparison between Fig 1 and 2 showed how corn starch PV ranked last. In Fig 2, the profile showed a two steps gelatinization process due to the effect of the pudding ingredients especially sugar, milk powder and lipids. Sugars are a prevalent ingredient in a lot of starch-based foods, especially baked goods, and it can have a big impact on how well starch gelatinizes, by limiting water availability, lower water activity and form sugar bridge between starch chains. The temperature at which starch gelatinizes rose as the water activity of a sugar solution fell. Sugars are hydrophilic, which means they can compete with starch for free water. These characteristics can make it harder for amorphous lamellae to move about in starch granules. Second, sugars usually boost the temperatures at which starch gelatinizes because they modify the water activity and viscosity (Allan *et al.*, 2020). The enthalpy of starches and gelatinization temperature were observed to rise with sucrose, suggesting that the granular structure stabilized during heating. It seems that there are more ways for sucrose to delay starch gelatinization besides the interactions between sugar and water. Lower PV appears to be the result of sugar-starch interactions interfering with the granules' ability to swell in the crystalline and/or amorphous areas of the starch granules (Chiotelli *et al.*, 2000). Starch-lipid complexes slow down the delay the gelatinization and retrogradation of starch, and decrease its swelling power and solubility in food systems, thus the PV (Wang *et al.*, 2017). As a result, Fig. 2 profiles show that samples containing MKS had a greater final viscosity than the sample with CS alone. The hardness of the pudding at room temperature also exhibits this difference. As shown in Table 2, the presence of the

pudding ingredients had effect on all pasting properties parameters of CS including PV, BD, FV, SB. In terms of pasting temperature, Table 2 indicates that there was significant decrease with an increase in MKS in the blend. In a system with enough water, the influence of sugar on the starch pasting temperature is determined by the type of starch. Generally, the gelatinization temperature of starch increases in a limited water content. Based on the data shown in Table 2, it seems that a higher MKS content in the blend corresponds to a lower pasting temperature.

The increase in PV and FV of MKS blend is a proof of the MS granule size uniformity which enabled some kind of interaction with the pudding ingredients that raised the PV. The difference between the peak viscosity and the lowest viscosity attained during the holding stage and prior to the initial setback step is used to calculate the breakdown viscosity. In terms of breakdown, blends with 100% MKS displayed the most BD and 100% CS the least (Table 2). The BD ranked as 100% MKS > 75% MKS > 50% MKS > 0% MKS. The BD is correlated with the PV, since $BD = PV - \text{torque}$, the more viscous material takes higher torque to break. For many operations, a starch paste capacity to tolerate heat and shear stress is crucial. Thus, breakdown is defined as the hot paste stability or the degree to which the granules have disintegrated. Therefore, MKS's higher breakdown viscosity than CS's suggested MKS hot paste was more stable. The disordering of the gelatinized starch granule structure causes hot paste breakdown, and the extent of breakdown is determined by the difference in viscosity between the swollen and partially or completely disordered gelatinized granule states (Zhou *et al.*, 2015).

The rate and extent of breakdown depend on the type of starch, shear force and composition of the mixture (Gomand *et al.*, 2010). Because all other testing parameters (temperature, shear rate) are the same for both starches, the difference in BD between CS and MKS is therefore attributable to the kind of starch. The data in

Table 2 demonstrated that, despite pure CS exhibiting approximately 3.7 times more BD than MKS starch, the pudding including CS had a substantially lower BD than the pudding containing MKS starch. Actually, pudding with MKS showed almost seven times as much as CS.

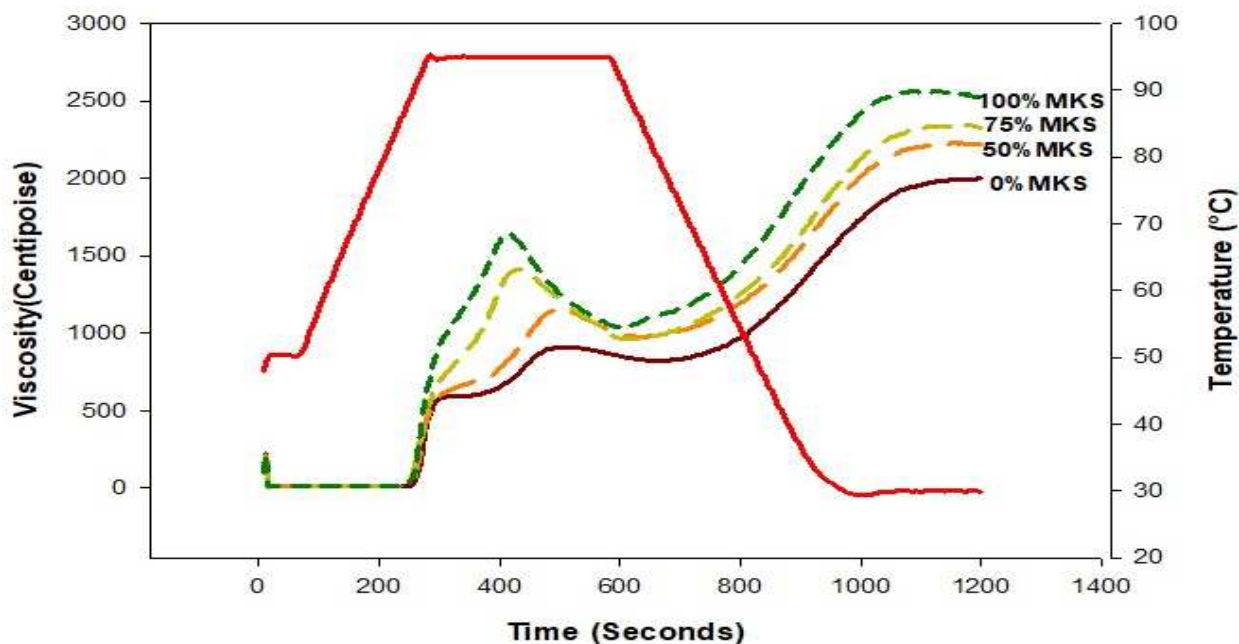


Fig. 2. RVA profile of pudding with mango kernel starch

Same trend was observed for the final viscosity. Consequently, the inherent interaction between the pudding components and MKS starch produced a higher viscosity, which in turn controlled the water movement. This may be explained by the length of the amylose molecules or by the ratio of amylose to amylopectin. According to reports in the literature, retrograded starch gels with short to medium amylose chains may enhance the gel's coherency and heat stability (Li *et al.*, 2021).

In terms of the setback (SB), which is closely linked to amylose retrogradation, blend containing MKS showed roughly 19% greater SB than blends containing CS. A stronger amylose network is indicated by a greater SB. Pure CS had a substantially greater SB than pure MKS when comparing the SB of pudding blends to pure starch; nevertheless, the SB of the pudding blends consisting of CS was weaker than the SB of the blends containing MKS, as seen by the lower SB. This indicates that additional ingredients inhibited amylose retrogradation by interacting with the amylose in blends with CS, which resulted in a decrease in SB. This may be explained by the amylose chain length in CS, which permitted interaction with the PB ingredients and so stopped the retrogradation that would have resulted in a decrease in SB.

Rheological Measurements

Dynamic Rheology: Most pudding products are starch pastes made from milk protein. The pudding's rheological qualities are somewhere between a gel and a liquid. Small-deformation rheology is commonly used to characterize gel microstructure. In the past, scientists suggested employing G' as a reference to establish rheological experimental conditions because it has more processing value than G'' , particularly for starchy products (Hsu *et al.*, 2000). Fig. 3 and 4 shows the frequency sweep of the blends. According to the profiles, higher MKS content resulted in lower G' , indicating reduced gel elasticity, although there was very minimal hysteresis between the samples at lower frequencies. Samples with 0% or 100% MKS showed higher or lower G' at lower frequencies, respectively, although the gap in G' between the samples increased at higher frequencies. The higher viscous property of MKS blend compared to the elastic will be shown later when we discuss the gel texture. While G' and G'' in Fig. 3 and 4 were both frequency dependent, G' was more so because it rose at higher frequencies. The sample with 75% and 100% MKS showed the same G' at lower frequency, but the sample with 100% MKS showed the lowest while the sample with 0% MKS had the highest

G' . This suggests a stronger amylose network because of the corn starch, however the 100% MKS counteracted this network, resulting in the lowest G' , which suggests a far lower degree of elasticity. Since the G' was conducted at 25 °C and the setback was determined at 50 °C, the RVA test did not reflect this data. Samples showed less variation in G'' compared to G' , and there was little increase in G'' , indicating that the gel's viscous property had not changed substantially. However, samples containing 100% MKS showed the greatest viscosity at

50 °C in the RVA. This demonstrated how sensitive the MKS gel was to shear and temperature changes. Therefore, the G' can be ranked as 0% MKS >75% MKS >50% MKS >100% MKS. However, mixes including both CS or MKS can be regarded as strong gels due to the substantial dependency at higher frequencies. These systems show intermediate rheology solid and gel, especially at high deformation, with the three-dimensional network fragmenting into smaller clusters as deformation increases.

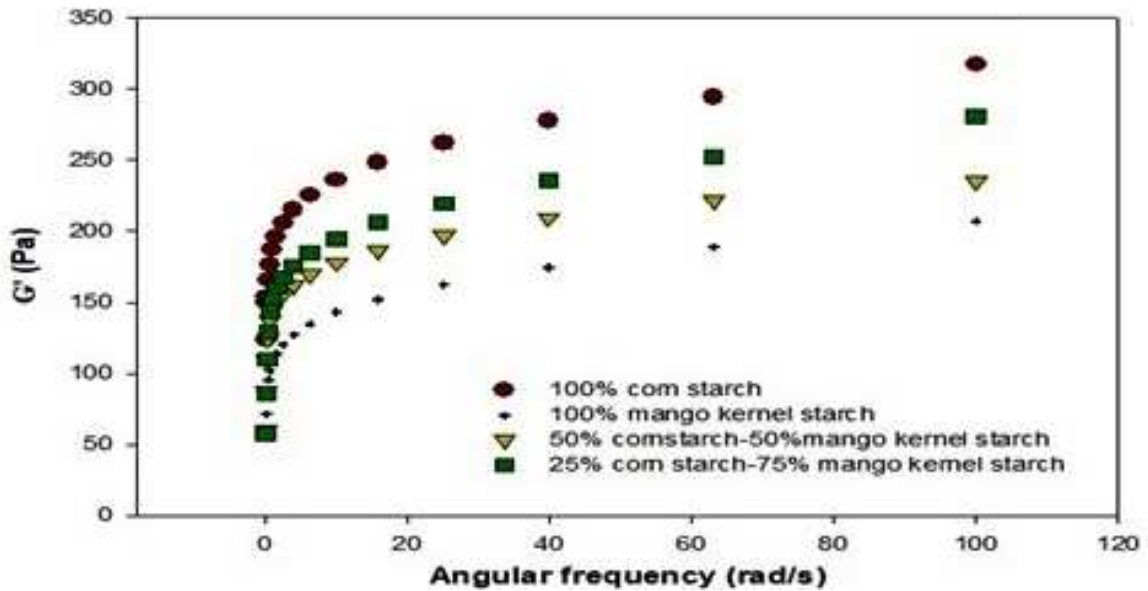


Fig. 3. G' profile of pudding with mango kernel starch

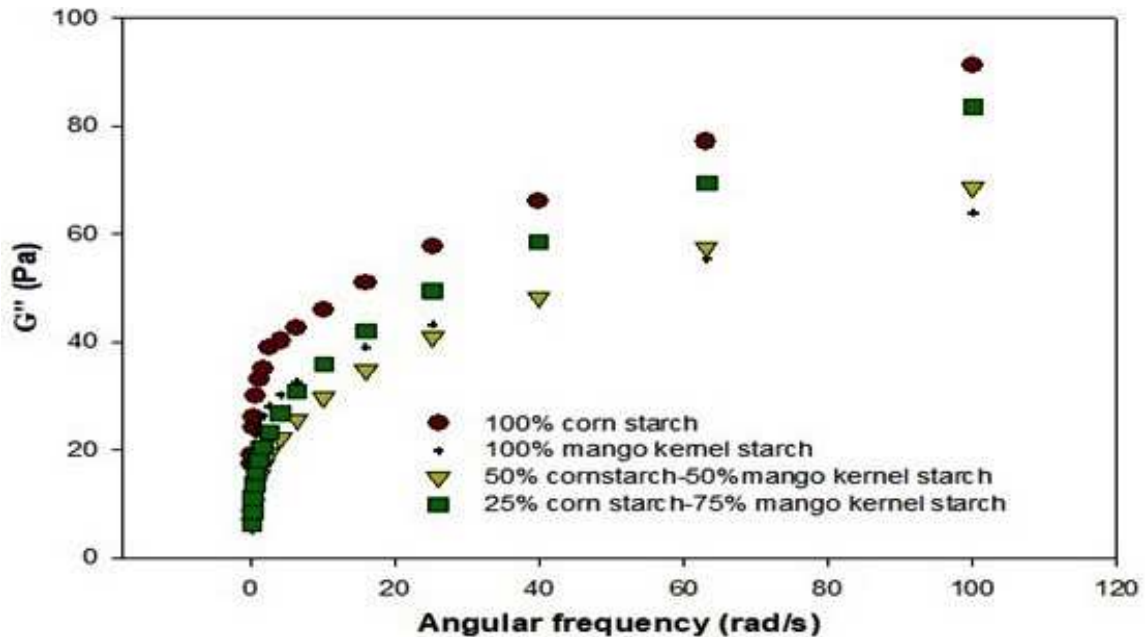


Fig.4. G'' profile of pudding with mango kernel starch

The relationship between the viscous and elastic parts of gels is described by the $\tan \delta$ ($= G''/G'$). $\tan \delta$

was less than 1.0 for every mix, regardless of temperature, content, or concentration (Fig. 5). This indicates that the gels have a distinct texture that is solid-like. $\tan \delta$ can increase by the decrease in G' at higher frequency. It is evident that the $\tan \delta$ increased as the frequency increased, irrespective of the blend's MKS starch content. Consequently, blends showed $\tan \delta$ 0.14, 0.17, 0.19, and 0.29 at 0.1, 1.0, 10, and 100 (rad/s), respectively. All samples showed a similar pattern, however samples with 50% MKS showed the highest $\tan \delta$ (0.23, 0.23, 0.25, and 0.31), indicating that MKS

content significantly influenced $\tan \delta$ values across frequencies. This suggests that the 50% MKS blend's G' decreased, which raised the $\tan \delta$. The smallest $\tan \delta$ was displayed at 0.1 (rad/s), signifying elastic property and the maximum at 100 (rad/s), indicating viscose behavior. Generally, blends containing 100% MKS have lower $\tan \delta$ values. $\tan \delta$ at 100 (rad/s) generally showed the highest value the least amount of variation within the 100 (rad/s) independent of the composition of the blend.

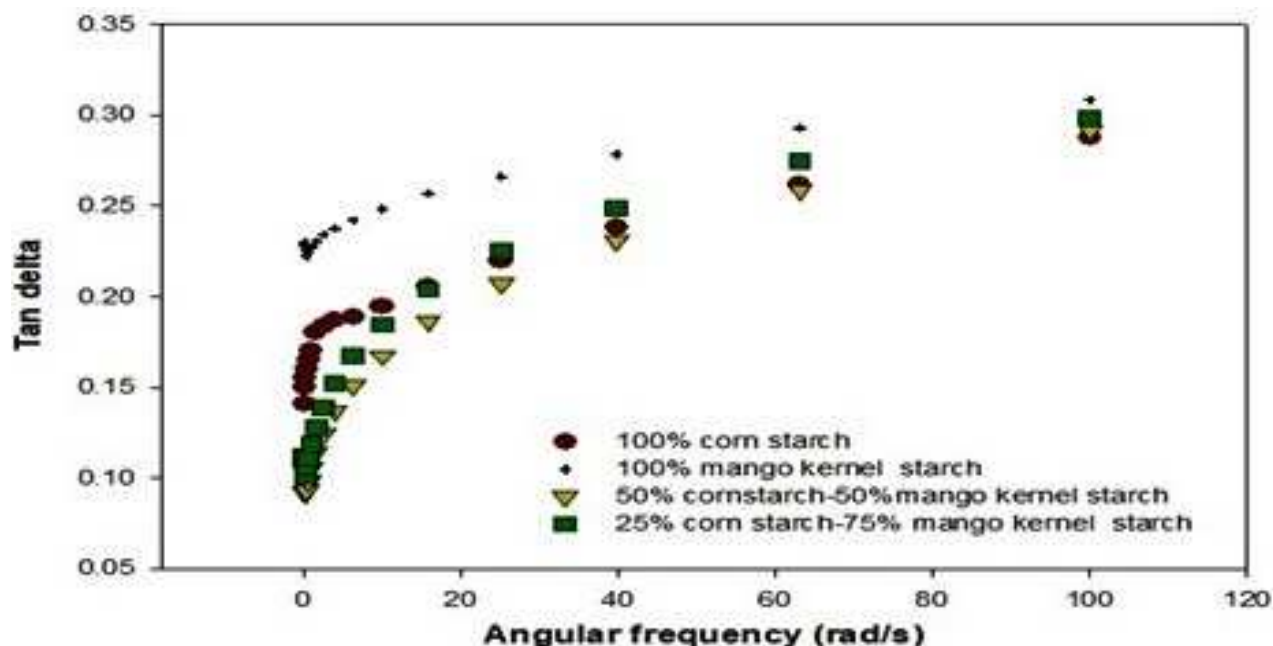


Fig.5. Tan delta profile of pudding with mango kernel starch

Steady Shear: The pudding batter at different MKS levels is shown by the shear stress versus shear rate graphs shown in Fig 6. The experimental data fit the Power Law model well ($R^2 > 0.99$). All formulations exhibited shear-thinning behavior, with apparent viscosity decreasing as shear rate increased. As noted by (Wang et al., 2017) this behavior can also be explained by breaking the entangled starch components (amylose and amylopectin) during shearing, indicating that the rate of entanglement disruption was higher than the rate of entanglement creation. Shear thinning or pseudoplastic behavior was linked to this phenomenon (Alamri et al., 2013; Valetudie et al., 1999). The flow behavior index ranged from 0.42 to 0.50. Table 2 displays the consistency coefficient (K) and flow behavior index (n) values that were acquired at 30, 50, and 50 °C using the DHR Hybrid Rheometer. regardless of the composition, all batter samples showed $n < 1$ (Table 3), showing pseudo-plastic behavior, which is consistent with the findings of other studies (Mandala & Bayas, 2004; Qasem et al., 2017). The shear behavior of gels varies

depending on the ingredients and their level of interaction (Yu et al., 2016). The apparent viscosity of all pudding blends gels decreased as shear was increased, indicating time-dependent thixotropic behavior. A larger MKS concentration causes the pudding batter's flow behavior index (n) to increase (Table 3). This rise in (n) demonstrated that, although the increase is nonlinear, the pseudoplasticity behavior decreases as the (n) number approaches 1. The n value is clearly higher at 50% and 75% MKS than it is at 0% and 100% MKS. This behavior suggests that higher MKS will result in less pseudoplastic behavior. This shows that the pudding ingredients and the 50–75% MKS work in synergy to create a more coherent gel. On the pudding hardness, which will be covered later, this behavior is observed. Molecular chain alignment along the applied shear field is the reason behind the thinning of starch gels under shear, which weakens the physical entanglement of polymeric chains at the starch-starch and starch-ingredients interfaces.

Table (3). Power law parameters of pudding flow curves at different MKS levels and temperatures.

MKS %	30°C			40°C			50°C		
	<i>n</i>	<i>K</i>	R ²	<i>n</i>	<i>K</i>	R ²	<i>n</i>	<i>K</i>	R ²
0	0.47±0.01	17.82±0.71	0.99	0.43±0.02	16.65±1.61	0.99	0.42±0.02	13.12±0.21	0.99
50	0.50±0.01	14.38±0.17	0.99	0.47±0.02	13.22±0.09	0.99	0.43±0.01	11.85±0.10	0.99
75	0.50±0.02	15.58±0.18	0.99	0.49±0.01	12.73±0.21	0.99	0.43±0.01	12.59±0.26	0.99
100	0.49±0.01	17.19±0.75	0.99	0.46±0.01	14.97±0.74	0.99	0.44±0.01	12.03±0.47	0.99

Power law model ($\tau = K\dot{\gamma}^n$) τ = Shear stress (Pascal), K = (Pa.s) and n = flow behavior index (dimensionless). This Table was used for Arrhenius equation; ¹100% corn starch; Mean carrying same letters in columns for particular MS content under specific parameter are non-significantly different from each other.

The power law model was shown to be appropriately acceptable for explaining the flow features of pudding blends containing CS or MKS within the investigated viscosity range, as indicated by the high coefficients of determination (R^2) that were observed. According to reports, the disentanglement of long chain molecules that results in a decrease in intermolecular resistance to flow under shear circumstances is the cause of the pseudo-plasticity of macromolecule solutions (Nurul *et al.*, 1999). Regarding K , a measure of the blends' viscosity, there was no obvious pattern between the blends; however, batter containing between 50 and 75% MKS consistently showed lower K and n values at all temperatures (Table 3). The texture of the finished product can be predicted based on the temperature-induced change in batter's viscosity, which is one of the parameters that determines its formation and stability (Shelke *et al.*, 1990). In the presence of 50–75% MKS, the K value as a function of temperature change was little. In contrast, the K value as a function of temperature changed considerably in the cases of zero and 100% MKS, which indicates pudding gel stability at

a temperature range of 30 to 50 °C due to MKS. Although, it was clear from the setback values for the CS and MS, CS gel should be stronger than MS, which is true for the pure starch, but in the blends, the setback of the samples containing MS was higher. This indicates stronger gel at 50 °C and at room temperature as it was shown by the gel hardness. Because a greater temperature is closely correlated with a lower viscosity of starch gels, the power law's flow index behavior often decreases as temperature rises (Haminiuk *et al.*, 2006). This was the case with every pudding blend that was tested. This starch does not display a rise in the n value at higher temperatures, as reported by Mohamed *et al.* (2021). Table 4 shows that samples with 50% and 75% MKS had activation energies (E_a) that were 36% and 30% lower than samples with 0% MKS, whereas samples with 100% MKS had an E_a that was 18% higher. A similar pattern was noted for the frequency factor μ , where samples with high E_a showed less interaction between blend components, suggesting a higher E_a requirement.

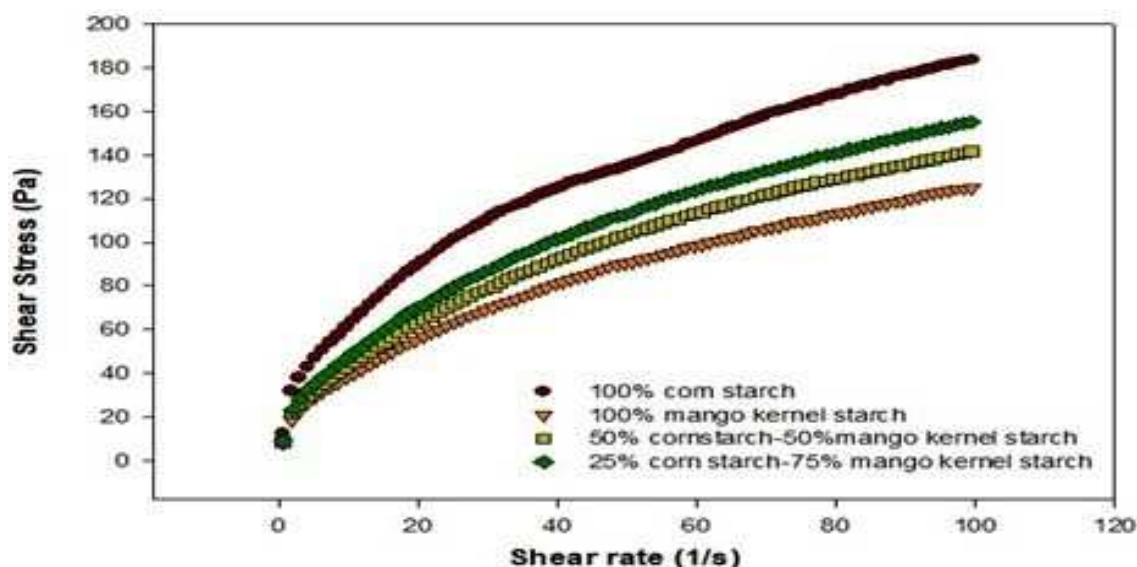


Fig.6. Steady shear profiles of the pudding with mango kernel starch

Table (4). Activation energy parameters of pudding containing various combinations at different MKS levels.

Mango kernel starch (MKS) %	μ^o (Pa s ⁿ)	E _a (J/mol K ⁻¹)	R ²
¹ 0	0.03954	12391	0.89
50	0.48405	7867	0.99
75	0.29510	8757	0.89
100	0.00952	14495	0.97

($\ln\mu a = \ln\mu_o + Ea/RT$); R= gas constant; T= absolute temperature (K); μa = apparent viscosity; μ_o (Pa sⁿ) = is the frequency factor at a reference temperature (30, 40 and 50 °C); Ea = activation energy (J/mol K⁻¹); ¹100% corn starch; Means with the same letters in columns for specific MS content under a given parameter are not substantially different.

The Herschel–Bulkley model's flow curves were fitted to the data, yielding the consistency index (K), flow behavior index (n), and yield stress (τ_0). For every sample, the coefficient of determination (R²) was 0.99 (Table 4). For 30, 40, and 50 °C, the consistency index (Pa.sn) ranged from 17–26, 14–23, and 4–8 (Pa.s), respectively. In contrast, Table 4 shows that the flow index varied between 0.42–0.47, 0.57–0.48, and 0.52–0.61 at 30, 40, and 50 °C, respectively. As a result, samples having 50 or 75 percent MKS were the least pseudoplastic, whereas samples having zero and 100 MKS were the most. This confirms the power law model presented in Table 3. According to the power law, the Herschel–Bulkley models *k* value dropped as temperature increased. The lowest shear given to start a flow is known as the yield stress (τ_0). In addition to being the minimal stress needed to start a flow, yield stress indicates the existence of entanglement or other interaction molecules in the material that need to be broken in order for flow to

occur at a significant rate (Achayuthakan & Supphantharika, 2008). While all of the pudding blends were pseudoplastic fluids ($n < 1$), they contrast in terms of their Herschel–Bulkley yield stress values in relation to temperature. The sample with 50% MKS showed the least yield stress at 30 °C, while the sample with 100% MKS showed the most. This shows how the pudding ingredients interacted more strongly in the presence of 100% MKS, necessitating greater stress to initiate the flow. On the other hand, the sample containing 50% MKS needed the least amount of stress to initiate the flow, suggesting a looser system with fewer interactions between its components. Samples with 0% and 100% MKS showed comparable yield stress at 40 °C, while the sample with 75% MKS showed the lowest yield stress among all the investigated samples, whereas the sample with 50% exhibited the most yield stress of all tested blends, indicating strong interaction.

Table (5). Herschel–Belkley fit of pudding flow curves at different MKS levels and temperatures

Mango starch %	30°C				40°C				50°C			
	τ_0	<i>n</i>	<i>K</i>	R ²	τ_0	<i>n</i>	<i>K</i>	R ²	τ_0	<i>n</i>	<i>K</i>	R ²
¹ 0	-10.29± 0.21	0.42± 0.01	23.59± 0.10	0.9 9	-10.57± 0.24	0.37± 0.01	23.24± 1.4	0.9 9	10.39± 0.85	0.52± 0.02	7.41± 0.24	0.9 9
50	-4.60± 0.02	0.47± 0.02	16.76± 0.21	0.9 9	-6.45± 0.03	0.42± 0.02	16.75± 0.71	0.9 9	15.75± 0.54	0.61± 0.02	4.14± 0.03	0.9 9
75	-6.71± 0.07	0.46± 0.01	19.06± 1.21	0.9 9	-1.61± 0.07	0.48± 0.02	13.55± 0.35	0.9 9	11.82± 1.02	0.55± 0.02	6.40± 0.09	0.9 9
100	-15.49 ±1.01	0.42± 0.01	25.74± 0.75	0.9 9	-10.09± 0.23	0.40± 0.01	20.87± 0.38	0.9 9	8.87± 0.32	0.52± 0.01	7.51± 0.31	0.9 9

Herschel–Bulkley model ($\tau = \tau_0 + K\dot{\gamma}^n$); τ = Shear stress (Pascal), τ_0 = the yield stress (Pascal), *K*= (Pa.s) and *n*= flow behavior index (dimensionless); ¹100% corn starch; Means with the same letters in columns for specific MS content under a given parameter are not substantially different.

Gel Texture: The textural parameters examined include hardness, defined as the force necessary for sample deformation; cohesiveness, representing the strength of internal bonding within the sample; and gumminess, which quantifies the energy needed to break down a semi-solid food in the mouth until it is ready to swallow (calculated as hardness multiplied by cohesiveness). After being stored overnight, the texture of the gels was assessed (Table 6). The pudding blends showed a

significant ($p < 0.05$) increase in hardness as compared to the 0% MKS. One can rank the samples as follows: 50% MKS > 75% MKS > 100% MKS > 0% MKS. The sample with 0% MKS showed the least amount of setback in relation to the RVA setback as well as the hardness (remember, the setback was measured at 50 °C and the hardness at 25 °C). Because the 100% MKS ranked first in setback and nearly last in hardness, there was a significant shift between the two metrics. The

toughest gels and moderate setback were observed in the 50% and 75% MKS blends. It seems that the pudding ingredients, particularly lipids, inhibited amylose retrogradation, as evidenced by the softer gel in the sample containing 0% MKS (100% corn starch). This suggests that the amylose chains of MKS and corn starch are different. This was demonstrated by the RVA setback, which showed the least amount of setback in samples containing only corn starch. As the hardness increased the pudding gel's cohesiveness weakened. This indicates

that the force required to penetrate the gel and the force required for deform it differ. Stated otherwise, the gel exhibits coherence at the surface when corn starch is included, but becomes softer on the surface upon the addition of MKS. therefore, samples with MKS are harder as a gel but easier to penetrate. Since there was no obvious pattern to the gumminess, the samples are sorted as follows: 50% MKS > 0% MKS > 75% MKS > 100% MKS. The 100% MKS sample required the least amount of energy to chew, followed by the 75% MKS sample.

Table (6). Effect of replacement of corn starch with MKS on texture

%MS	Hardness (g)	Cohesiveness	Adhesiveness (m J)	Gumminess (g)
0 ¹	6.75±0.01 ^d	0.87±0.00 ^a	0.08±0.00 ^c	5.86±0.05 ^b
50	7.75±0.02 ^a	0.84±0.00 ^b	0.10±0.00 ^b	6.49±0.03 ^a
75	7.50±0.01 ^b	0.74±0.00 ^c	0.25±0.00 ^a	5.55±0.01 ^c
100	7.00±0.01 ^c	0.59±0.00 ^d	0.25±0.00 ^a	4.11±0.01 ^d

¹100% corn starch; Means with the same letters in columns for specific MS content under a given parameter are not substantially different.

Sensory Evaluation: Table 7 displays the average findings of the sensory evaluation of the prepared pudding using the investigated mango kernel and corn starch. The assessors found that samples made with corn starch performed significantly ($p > 0.05$) better in terms of color, oral thickness, and external thickness when compared to ones made with whole mango kernels.

Puddings with 50% and 75% MKS received higher scores for melting and smoothness. The 50% and 100% MKS pudding contents received higher flavor ratings than the other mixtures. The pudding sample with 50% MKS was rated most acceptable by panelists, followed by the sample with 0% MKS.

Table (7). Effect of replacement of corn starch with MKS on sensory attributes

%MKS	Color	External thickness	Oral thickness	Melting	Smoothness	Flavor	Overall acceptability
XX ²	3.85±0.01 ^d	3.97±0.01 ^c	4.63±0.02 ^b	4.38±0.01 ^b	4.21±0.01 ^c	4.42±0.01 ^b	4.29±0.01 ^b
0	4.00±0.01 ^a	4.83±0.01 ^a	4.88±0.02 ^a	4.38±0.01 ^b	4.54±0.01 ^a	4.17±0.01 ^c	4.49±0.01 ^a
50	3.88±0.01 ^b	4.08±0.02 ^b	4.00±0.01 ^c	4.58±0.01 ^a	4.42±0.01 ^b	4.50±0.01 ^a	4.51±0.02 ^a
75	3.88±0.2 ^b	3.75±0.01 ^d	3.92±0.01 ^d	4.50±0.01 ^a	4.08±0.01 ^d	4.42±0.2 ^b	4.19±0.01 ^c
100	3.67±0.01 ^c	3.21±0.01 ^c	3.71±0.01 ^c	4.04±0.01 ^c	3.79±0.02 ^c	4.58±0.01 ^a	3.97±0.01 ^d

¹100% corn starch; ²XX= commercial control; Means with the same letters in columns for specific MS content under a given parameter are not substantially different.

Conclusions: Pudding samples that contained ground mango kernel starch (MKS) instead of corn starch showed superior rheological and sensory properties compared to the commercial sample. In terms of pudding setback, final viscosity, and peak viscosity, the RVA results demonstrated MKS's superior performance. The dynamic rheological tests showed that MKS performed better than expected, particularly at the 50 and 75% MKS levels. Comparing MKS pudding to commercial samples and corn starch pudding, panellists accepted MKS pudding received higher overall acceptability scores. The best-performing samples had a 50 and 75% MKS content. Therefore, MKS is a cost-effective and practical alternative starch source for pudding formulations.

Conflicts of interest: There is no conflict, according to the authors.

Data availability: The publication presents the original contributions of the study. For further inquiries, please reach out to the corresponding author.

Acknowledgements: The authors appreciate the support from the Ongoing Research Funding Program, (ORF-2025-1458), King Saud University, Riyadh, Saudi Arabia.

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