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Research Article

Black plum (pulp and peel) flours effects on wheat dough thermal and rheology properties

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Abstract

Plant-based dietary fibers play a fundamental role in improving human health. The objective of this study is to determine the effect of incorporating black plum powders (pulp and peel) on the thermal and rheological properties of wheat dough. The test dough cake samples were prepared with 0% (control), 3%, 5% and 7% replacement of wheat flour with black plum pulp and peel powders. Thermal and rheological properties of these doughs were determined using Differential Scanning Calorimetry (DSC) and rheometer, respectively. Thermal analysis showed a decrease and an increase in the peak temperature (T_p) (65.90 ± 0.01 - $65.22 \pm 0.03^\circ\text{C}$) and gelatinization enthalpy (ΔH) (5.54 ± 0.33 - 6.71 ± 0.45 SI) of the wheat flour-black plum pulp or peel powder mixture, respectively. However, the gelatinization temperature range (T_F - T_i) of the wheat flour starch did not significantly ($P > 0.05$) vary. The doughs exhibited shear thinning (pseudo-plastic) behavior and a typical solid-elastic behavior. Both powders (pulp and peel) did not have significant effects ($P > 0.05$) on the rheological properties (flow and viscoelasticity) of the dough. Black plum pulp (FVPu) and peel (FVPe) powders can be partially incorporated into wheat flour in the preparation of cakes without significant modifications to the properties of wheat dough.

Keywords

wheat flour, viscoelasticity, temperature, gelatinization, dietary fiber

Abbreviations

FVpu – Black plum pulp flour; FVpe – black plum peel flour; ΔH – gelatinization enthalpy; PHI – peak height index; R – gelatinization range; T_F – end temperature; T_o – onset temperature, T_p – Peak temperature.

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Introduction

The black plum, also known as the savanna plum (*Vitex doniana*), is a tropical drupe-type fruit from the Lamiaceae family (Nouroudine et al. 2024). It comes from the black plum tree, a spontaneous species widely distributed in most tropical countries, including Nigeria, Sudan, Kenya, Benin, Senegal, Cameroon, Ghana, Guinea, Côte d'Ivoire, etc. (Shaban 2011; WAHO 2013; Salih et al. 2015; Ouattara et al. 2016; Traore et al. 2018; Dadjo 2018). In Côte d'Ivoire, it is mainly found in the northern regions (Korhogo, Tingrela, Ferkessedougou, etc.) (Tiébré et al. 2016), Northwest (Séguéla) (Ambé 2001), Northeast (Bondoukou) (Ouattara et al. 2016) and central regions (Yamoussoukro, Ahierémou, Pakobo etc.) (Béguin 1992). The black plum is highly appreciated in these areas due to its attractive flavor. The pulp of the black plum is rich in vitamins, particularly vitamins A, B, and C, as well as minerals such as calcium (355.30 – 389.52 mg.100 g⁻¹ dry matter), magnesium (221.00 – 255.5 SI), and phosphorus (118.00 – 179.00 SI) (Traore et al. 2022). The pulp and peel of the plum contain gallic acid, protocatechuic acid, p-hydroxybenzoic acid, m-hydroxybenzoic acid, caffeic acid, chlorogenic acid, m-coumaric acid, and cinnamic acid. The pulp is a good source of cinnamic acid (1046.14 SI), while the peel is a main source of gallic acid (5175.98 SI) (Traore et al. 2021). These nutrients give it the ability to contribute to strengthening the immune system and bones and preventing degenerative diseases such as osteoporosis, cardiovascular diseases, cancers, etc. (Bansal et al. 2016; Gutiérrez-Grijalva et al. 2016; Rahman et al. 2022). Furthermore, the pulp and peel of the black plum are also rich in dietary fiber (34.79 – 39.83% for the pulp and 46.38 – 50.21% for the peel) (Traore et al. 2022). It can be used as an ingredient to improve the nutritional quality of food preparations, especially bakery products. Dietary fibers, due to their water retention capacity, play an important role in intestinal transit (Ötles & Ozgoz 2014; Merenkova et al. 2020; Pérez-Jiménez 2024). They stimulate intestinal contractions and promote the bacterial activity of the colon (Edwards 1990). They play an essential role in reducing the risk of type 2 diabetes, cardiovascular diseases, and colon cancer by slowing down the digestion and absorption of macronutrients and reducing the

contact time of carcinogenic substances with the intestinal lumen (Kaczmarczyk et al. 2012). The bakery sector is rapidly growing and becoming popular worldwide among consumers for its ready-to-eat products such as cakes. Cakes are among the most consumed and appreciated bakery products due to their taste, flavor, affordability for all social classes, and relatively long shelf life (Sudha et al. 2007). In recent decades, the enrichment of cakes with fiber to improve public health has been the subject of numerous research studies. Cakes have been enriched with fiber by adding powder from various plant products, such as pineapple (pulp and peel), passion fruit, apple, grapefruit, mango, lemon, orange, apricot, etc. (Vergara-Valencia et al. 2007; Korus et al. 2020; Nisar et al. 2021; Jose et al. 2022; Akhter et al. 2024; Kausar et al. 2024; Toan and Han 2024).

A black plum tree can produce about 1 ton of fruit. In Côte d'Ivoire, its fruits are widely consumed raw and often used to make refreshing drinks. After consuming the desired quantity of fruit, the surplus is left behind in plantations and villages. However, given their high fiber content, black plum fruits could be used as an ingredient to enrich cakes with fiber, especially since previous studies have reported many benefits associated with the inclusion of dietary fiber in human diets. This study aims to determine the effects of incorporating black plum powders (pulp and peel) on the thermal and rheological properties of wheat dough.

Materials and Methods

Materials. Black plums (*Vitex doniana*) were collected in the Yamoussoukro area (Côte d'Ivoire). The fresh fruit was harvested and washed with tap and distilled water. After drying with a paper towel, the fruit pulp and peel were separated by hand using a stainless-steel knife. Each part was then dried in an oven (Memmert U30 Gemini BV GmbH, Germany) at 50°C for 24h and milled (ZBK220077-88 LW74d(B) A (China). The average particle size of the milled pulp and peel was less than 200 µm. The milled pulp and peel were packed in polyethylene bags with a vacuum packager and then stored in a freezer (-10 ± 5°C) until use.

Cake dough tests

Cake dough preparation. The cake formulas at three different black plum levels are shown in Table 1. The ingredients used in the cake formulas were wheat flour, sucrose, margarine, fresh eggs, skimmed milk, baking powder, and vanilla. The egg yolk and sugar were mixed in a mixer (Kitchen Aid 900; Whirlpool Corporation, St. Joseph, Michigan, USA) for 5 minutes. The milk was then added to this mixture and mixed for 4 min until a semi-firm

dough was formed. The softened margarine (1 min at 170°C) was then added, and the mixture was continued for an additional 4 min. Next, the flour and baking powder were added, and the entire mixture was mixed for 4 min. After that, the egg white beaten to stiff peaks was incorporated into the mixture and mixed for 3 min. The test dough cake samples were prepared with 0% (control), 3%, 5% and 7% replacement of wheat flour with black plum pulp and peel powder.

Table 1. Cake formula

Ingrédients	Black plum flour content (pulp and peel), g.300 g ⁻¹ of dough				
	% mass	0 ^a	3	5	7
Wheat flour	29.42	88.26	85.61	83.85	82.08
Black plum flour	-	0	2.65	4.41	6.18
Eggs white	11.77	35.31	11.77	35.31	35.31
Sugar	26.48	79.44	26.48	79.44	79.44
Milk skimmed	17.65	52.95	17.65	52.95	52.95
Softened margarine	11.77	35.31	11.77	35.31	35.31
Egg yolk	2.35	7.05	2.35	7.05	7.05
Yeast	1.02	3.1	1.02	3.1	3.1

^a Prepared respectively with 0, 3, 5, and 7 g/29.42 g of cake flour samples replaced with black plum flour.

Thermal properties of cake doughs. Thermal properties were evaluated using Differential Scanning Calorimetry (DSC Q1000, Belgium). The instrument was calibrated with indium. A quantity of flour (100% wheat flour or wheat flour + black plum powders) of 3 mg was mixed with distilled water to reach a final moisture content of 10%. To maintain the final moisture content at 10%, a saturated solution of NaNO₂ (*aw* = 0.64 at 25°C) was used. Samples were heated from 20°C to 110°C at a heating rate of 10°C.min⁻¹. The onset temperature (*T*_o), peak temperature (*T*_p), end temperature (*T*_F), and gelatinization enthalpy *H* (SI of dry starch) were determined according to the methods of Krueger et al. (1987).

Rheology of cake doughs. Rheological analysis was performed using a controlled-stress rheometer (Rheometer MCR series from Anton Paar, USA) with parallel plate geometry (50 mm diameter). Before the rheological analyses, a thin layer of petroleum jelly was applied to cover the exposed surfaces of the paste to prevent edge drying. Subsequently, the samples were left for 5 min to

allow for relaxation. The cake batter was placed between parallel plates with a gap of 1 mm. The rheological analyses were conducted at 25°C. Stress sweep tests ranging from 0.1 to 20 Pa and a frequency of 10 Hz were performed to determine the maximum stress in the linear viscoelastic region of all samples. The applied stress was then adjusted to remain within a linear regime during the frequency dependence test. Oscillatory tests were carried out with a different aliquot of the same samples at a frequency of 3 Hz and an amplitude of 0.1%. The dynamic rheological properties of the samples were evaluated by the storage modulus *G'* (elastic modulus) and the loss modulus *G''* (viscous modulus). Flow measurements were determined by the shear stress (σ) as a function of the shear rate ($\dot{\gamma}$) ranging from 0 to 50 s⁻¹. Over a period of 200 s, one hundred points on the logarithmic scale were measured. The flow curves were fitted to the Herschel-Bulkley law $\sigma = \sigma_0 + K \dot{\gamma}^n$, which provided the consistency coefficient *K*, a function of viscosity, and the flow index *n*.

Statistical analysis of results. Average values with standard deviation errors are reported. Significant differences at 95% confidence were determined by the analysis of variance (ANOVA) was performed using RStudio Version 1.2.1335 2009 - 2019. Tuckey's test was used to describe means. All trials were replicated three times.

Results and Discussion

Effect of wheat-flour and wheat-flour – black plum peel and pulp powders on the gelatinization temperature of doughs. Fig. 1 shows the differential scanning calorimetry (DSC) thermograms for wheat flour samples and wheat flour blended with black plum peel and pulp powders. These thermograms, revealing the behavior of the samples upon heating, highlight endothermic peaks. The average gelatinization transition temperatures, as well as the gelatinization temperature ranges and peak height indices, are calculated and presented in Table 2.

A thorough understanding of the phase transitions of starch in certain products is crucial in food processing. The average thermal transition of starch is gelatinization. Gelatinization is an order-disorder phase transition involving the diffusion of water into starch granules, hydration, swelling, heat absorption, loss of birefringence and crystallinity, and leaching of amylose (Biliaderis et al. 1980). The gelatinization process is represented in the DSC as an endothermic peak. Endothermic peaks for the control sample and samples with 3 to 7% incorporation of black plum pulp and peel powders appear between 58.97°C and 81.37°C. The transition temperatures (T_0 and T_F) of the analyzed samples show no significant differences among them. However, the peak height indices (PHI) of wheat flour samples with incorporated black plum pulp and peel powders are significantly higher than that of the control (0.88 ± 0.06 SI °C). The PHI values for samples with incorporated black plum pulp and peel powders show no significant difference between them, with average values of 1.06 ± 0.05 (SI°C). Additionally, the gelatinization ranges of the samples average 20.63°C. Thermal analysis results showed that the peak gelatinization temperature of the wheat flour – black plum peel or pulp powder mixture decreased from 65.87°C to

65.22°C with increasing amounts of black plum powders (Fig. 2). In contrast, an opposite trend was observed for the starch gelatinization enthalpy (from 5.53 SI to 6.71 SI). These results could be attributed to the increasing reduction in the amount of starch in the wheat flour due to the incorporation of increasing amounts of black plum powders (pulp and peel). In other words, the observed decreases and increases in T_p and ΔH (enthalpy) respectively, can be attributed to the dilution of wheat starch with black plum pulp and peel powder. At this level, wheat starch granules had more opportunity to absorb water, thus exposing a larger proportion of crystalline areas, primarily due to amylose content. This explains why a higher energy (melting enthalpy) was needed to break the intermolecular bonds in the wheat starch granules to achieve gelatinization (Singh et al. 2004).

Moreover, several studies have shown negative correlations between DSC parameters (T_p and ΔH) and the water content of the product. Wang et Kim (1998) reported that starch in waxy corn starch melted at 230°C during DSC scanning with a water content of less than 61%. The same starch gelatinized at a temperature of 65°C with a water content greater than 61%. For dry potato material, the endothermic peak temperature increased to higher temperatures of 72, 88, 97, and 103°C when moisture contents were 40%, 30%, 23%, and 18% (w/w), respectively (Liu et al. 2002). According to Louaer et al. (2008), higher water content leads to a greater increase in thermal capacity during gelatinization. Thus, heat is transferred more quickly to the starch granules, leading to their melting at lower temperatures. Furthermore, Ottenhof et Farhat (2004) revealed in their work on corn starch that when the water content is insufficient, the peak temperature increases, which lowers the gelatinization enthalpy, indicating incomplete gelatinization. However, the changes in T_p and ΔH in our study suggest a more complete gelatinization of the starch in wheat flour with incorporated black plum pulp and peel powders compared to the starch in the control flour. Additionally, the slight decrease in the gelatinization enthalpy of starch in wheat flour with 5 and 7% of incorporated black plum powders (pulp and peel) suggests a possible effect of other components in the black plum powder on starch

gelatinization or dilution by non-amylaceous components. For the same gelatinization temperature ranges, the control sample exhibited a lower PHI value. The peak height index (PHI) indicates the relative shape of the endotherm (Correia et Beirão-Da-Costa 2012). According to Krueger et al. (1987), a high PHI indicates a large and narrow endotherm, while a low PHI indicates a short endotherm. Thus, considering the results regarding the PHI of the samples, it can be concluded that samples with black plum powders

(pulp and peel) all exhibited significantly large and narrow endotherms of similar shape, whereas the control sample showed a short endotherm. Furthermore, the gelatinization temperature range of the starch in wheat flour did not significantly vary despite the incorporation of black plum pulp and peel powders. This result suggests that the incorporation of black plum powders (pulp and peel) did not cause any transformation in the crystalline regions of the starch.

Table 1. Thermal properties (DSC) of wheat flour and wheat flour with black plum pulp and skin powders incorporated at different percentages

Samples	T ₀ , °C	T _F , °C	PHI, SI °C	R, °C
Control	59.46 ± 0.26 ^a	81.37 ± 3.39 ^a	0.88 ± 0.06 ^a	21.91 ± 3.13 ^a
3%FVPu	58.97 ± 0.39 ^a	79.55 ± 2.18 ^a	1.08 ± 0.00 ^b	20.58 ± 1.79 ^a
3%FVPe	59.26 ± 0.20 ^a	80.63 ± 0.57 ^a	1.09 ± 0.00 ^b	21.37 ± 0.67 ^a
5%FVPu	59.39 ± 0.00 ^a	78.36 ± 0.68 ^a	1.05 ± 0.02 ^b	18.97 ± 0.68 ^a
5%FVPe	59.13 ± 0.29 ^a	80.07 ± 1.48 ^a	1.08 ± 0.01 ^b	20.93 ± 1.19 ^a
7%FVPu	59.00 ± 0.07 ^a	79.44 ± 0.21 ^a	1.03 ± 0.00 ^b	20.43 ± 0.13 ^a
7%FVPe	59.75 ± 0.30 ^a	80.01 ± 0.83 ^a	1.04 ± 0.00 ^b	20.25 ± 0.53 ^a

To = onset temperature, T_F = end temperature, R = gelatinization range (T_F - T₀); ΔH = gelatinization enthalpy, PHI = peak height index ΔH / (T_p - T₀), T_p = Peak temperature. For each determined parameter, values followed by the same uppercase letter are not significantly different at p > 0.05, Tukey's test.

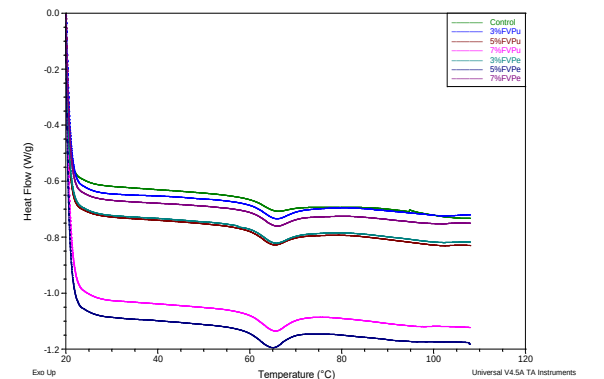


Figure 1. Typical DSC thermograms of wheat flour samples (control) and wheat flours with black plum pulp and skin powders incorporated at different percentages

Effect of wheat-flour and black plum peel and pulp flour blends on the rheological properties of dough

• **Flow behavior.** The flow behavior of the doughs is illustrated in Fig. 3 and 4. These figures show

that the shear stress (Pa) increases with the shear rate (1/s), while the apparent viscosity decreases.

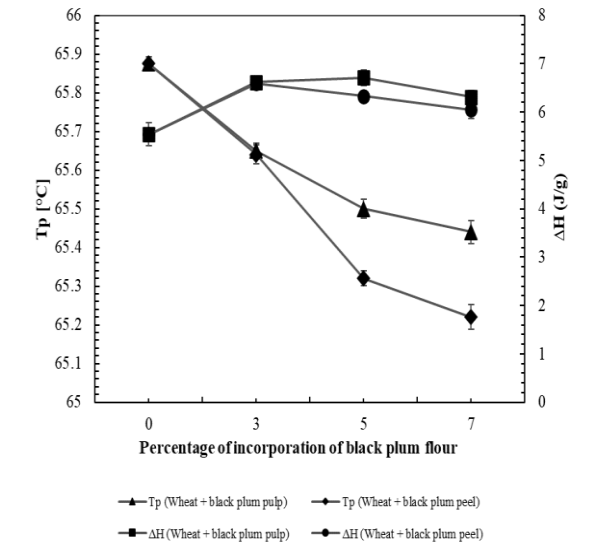


Figure 2. Peak temperature (Tp) and enthalpies (ΔH) of wheat flour and black plum pulp and peel flour mixtures (0 - 7%)

Moreover, the increase in the amount of black plum pulp and peel powders does not affect the apparent viscosity of the cake batter. From Fig. 3, it can be seen that at all shear rate values, the shear stresses of the samples with 3% black plum pulp flour (3%FVPu) and 3% black plum peel flour (3%FVPe) are higher compared to other cake batters, including the control. In contrast, the shear stress values for batters with 5% black plum peel flour (5%FVPe) and 7% black plum peel flour (7%FVPe) are lower than those of the other batters. The flow curves of the cake batter samples exhibited shear-thinning (pseudoplastic) behavior. Indeed, for pseudoplastic materials, the apparent viscosity decreases as the shear applied to the liquid increases. This is because the intermolecular interactions in the system break down under shear, due to microstructural alignment with the direction

of flow (Song et al. 2006; Demirkesen et al. 2010), leading to a decrease in apparent viscosity with increasing shear. The same behavior was observed by Kirbaş et al. (2019) in wheat cake batter containing apple, orange, and carrot residues, by Demirkesen et al. (2010) in gluten-free bread dough, and by Turabi et al. (2008) in rice cake batter. Regarding the effect of incorporating black plum pulp and peel powders on the rheological properties of the dough, all dough samples were well-fitted to the Hershel-Bulkley model, as presented in Table 3, indicated by the high determination coefficients (0.93 – 0.99). The flow behavior index (n) provides information on whether the flow is shear-thinning ($n < 1$) or shear-thickening ($n > 1$) (Sakiyan et al. 2004). If $n = 1$, the model reflects Newtonian behavior.

Table 3. Herschel-Bulkley model constants describing the flow curves of cake batter at different incorporation levels of black plum pulp and peel flours

Percentage of incorporation	Black plum flours				
	Pulp	Peel	n	K (Pa.s ⁿ)	r ²
0	0	0	0.11 ± 0.00 ^a	571.54 ± 1.39 ^b	0.98 ± 0.01 ^a
3	3	0	0.18 ± 0.01 ^a	309.83 ± 39.74 ^{ab}	0.93 ± 0.08 ^a
3	0	3	0.19 ± 0.03 ^a	267.31 ± 66.79 ^a	0.99 ± 0.00 ^a
5	5	0	0.14 ± 0.04 ^a	376.51 ± 43.39 ^{ab}	0.97 ± 0.00 ^a
5	0	5	0.14 ± 0.01 ^a	410.85 ± 46.02 ^{ab}	0.97 ± 0.01 ^a
7	7	0	0.19 ± 0.01 ^a	448.29 ± 52.02 ^{ab}	0.95 ± 0.01 ^a
7	0	7	0.19 ± 0.02 ^a	438.16 ± 62.28 ^{ab}	0.96 ± 0.01 ^a

For each determined parameter, values followed by the same uppercase letter are not significantly different at $p > 0.05$ according to Tukey's test. K: consistency index; n: flow behavior index.

For all cake formulations, the n values were less than 1, indicating that the cake batter was shear-thinning (pseudoplastic). This confirms the pseudoplastic flow behavior of the cake batters, as demonstrated by the shape of the flow curves. The consistency index (K) is an important parameter for evaluating the dough's air retention capacity during mixing (Sakiyan et al. 2004; Gomez et al. 2010; Tan et al. 2015). It influences the product quality, particularly its volume. In this study, the consistency index of the cake batters ranged from 267.31 to 571.57 Pa.sⁿ. All samples containing black plum pulp and peel powders had consistency indices similar to the control batter. The batter with

3% FVPe had the lowest consistency index (K). However, this low consistency value of the batter with 3% FVPe did not have any significant impact ($P > 0.05$) on its flow index. Lebesi and Tzia (2011) and Aydogdu et al. (2018) observed an increase in the consistency index of dough with the addition of fibers primarily composed of insoluble fibers. According to these authors, due to the higher water-binding capacity of fibers, water absorption increases. This reduces the amount of free water available, which is responsible for particle movement in the dough, resulting in a higher consistency index. However, in our study, despite the high water absorption capacity and fiber content

of black plum pulp and peel powders, no significant impact was generally observed on the consistency index of the dough. This result could be attributed to the effect of the fibers in the black plum peel and pulp powders on the internal structure of the dough. Indeed, the observation of the microstructure of dough containing fibers by [Martinez et al. \(2014\)](#) revealed that insoluble fibers remained almost unchanged and became more rounded due to the presence of starch. The structures thus became larger and more irregular. In contrast, soluble fibers dissolved in water and coated starch granules, reducing the hydration capacity of starches. Consequently, the consistency of the dough was reduced. Moreover, [Sabanis et al. \(2009\)](#) previously indicated that insoluble fibers increased the consistency of the dough. Additionally, [Turkut et al. \(2016\)](#) also reported that increasing the amount of fibers led to an increase in the water absorption capacity of the dough due to the high amount of soluble dietary fibers contained in these fibers. A similar result was also obtained by [Gomez et al. \(2010\)](#). In plain terms, the black plum pulp and peel powders do not affect the flow properties of the dough.

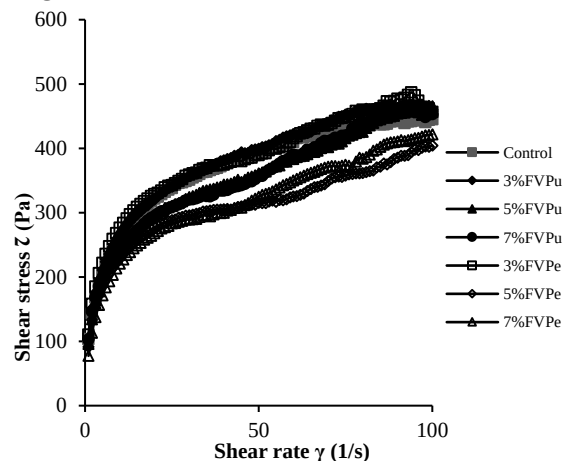


Figure 3. Flow curve showing the relationship between shear rate and shear stress of cake batters. 3%FVPu, 5%FVPu et 7%FVPu: Black plum pulp flour at 3%, 5%, and 7% incorporation levels. 3%FVPe, 5%FVPe et 7%FVPe: Black plum peel flour at 3%, 5%, and 7% incorporation levels

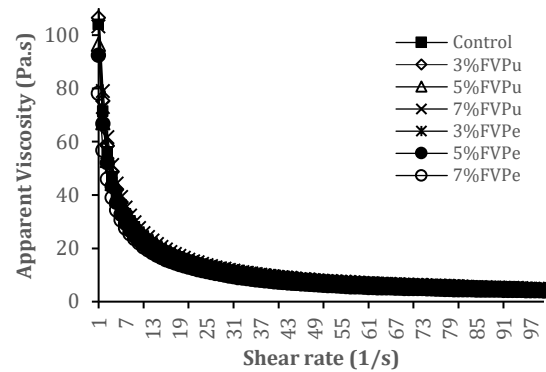


Figure 4. Flow curve showing the relationship between shear rate and apparent viscosity of cake batters

3%FVPu, 5%FVPu et 7%FVPu: Black plum pulp flour at 3%, 5%, and 7% incorporation levels.
3%FVPe, 5%FVPe et 7%FVPe: Black plum peel flour at 3%, 5%, and 7% incorporation levels.

• **Viscoelastic Behavior.** The viscoelastic properties of wheat flour and substituted wheat flour examined using dynamic oscillation tests are illustrated in Fig. 5a-d. The oscillation test and the values of the storage modulus (G') and loss modulus (G'') of cake batter with 3%, 5%, and 7% incorporation of black plum pulp and peel powders revealed that in all samples, G' values increased with shear duration while G'' values remained almost unchanged. The storage modulus was found to be higher than the loss modulus, indicating a solid-elastic behavior of the cake batters. However, a simultaneous decrease in viscoelastic properties (G' and G'') of the batter was observed with the addition of black plum peel powder at 5% and 7% incorporation levels. This may be due to the lower water absorption capacity of the black plum peel powder compared to the pulp. The addition of this peel powder could have caused a dilution effect on gluten, disruption of the starch-gluten matrix, and changes in the cross-linking and structure of the biopolymers in the dough ([Balestra et al. 2011](#); [Liu et al. 2016](#); [Pathak et al. 2017](#)). At 3% incorporation, the amount was not high enough to induce a modification in the rheological properties of the cake batter. Previous studies ([Rosell et al. 2009](#); [Lebesi and Tzia 2011](#); [Bchir et al. 2014](#); [Turkut et al. 2016](#)) have also revealed changes in the viscoelastic properties of cake batter with the addition of fiber extracts or high-fiber food products. However, these modifications were

observed in the G' modulus and the loss tangent ($\tan \delta$) (Fig. 5d), translated respectively by an increase and a decrease in these properties. This is due to the reduced amount of free water available because of the addition of fibers or high-fiber food products. Thus, fibers, due to their high water absorption capacity, compete with the biopolymers (gluten and starch) in the wheat flour and absorb some of the water in the formulation. These results in a decrease for water, making the cake batter more consistent and thus more elastic (Sabanis et al. 2009; Gomez et al. 2010; Martinez et al. 2014). However, factors such as the conditions or environment of the food system in which the fibers are incorporated can influence their water absorption capacity. These conditions include pH, fiber concentration, and other ingredients (such as starch and sugars) in the food system with high water absorption capacity (Charis 2019). This could

explain the non-significant effect ($P>0.05$) of the two powders

(pulp and peel) of black plum on the rheological properties of the batter, particularly the loss tangent ($\tan \delta$) and flow index, despite the high water absorption capacities of these powders. The conditions of the food system in which the black plum powders are incorporated might have reduced the water absorption capacity of the fibers in these powders, leading to stability in the free water available. Water plays an important role in determining the viscoelastic properties of dough. Amjid et al. (2013) revealed that both G' and G'' moduli decrease as the water content of the dough increases. A minimal effect of dietary fibers on the viscoelastic behavior of the dough is desirable as it may indicate minor changes in baking performance (Balestra et al. 2011).

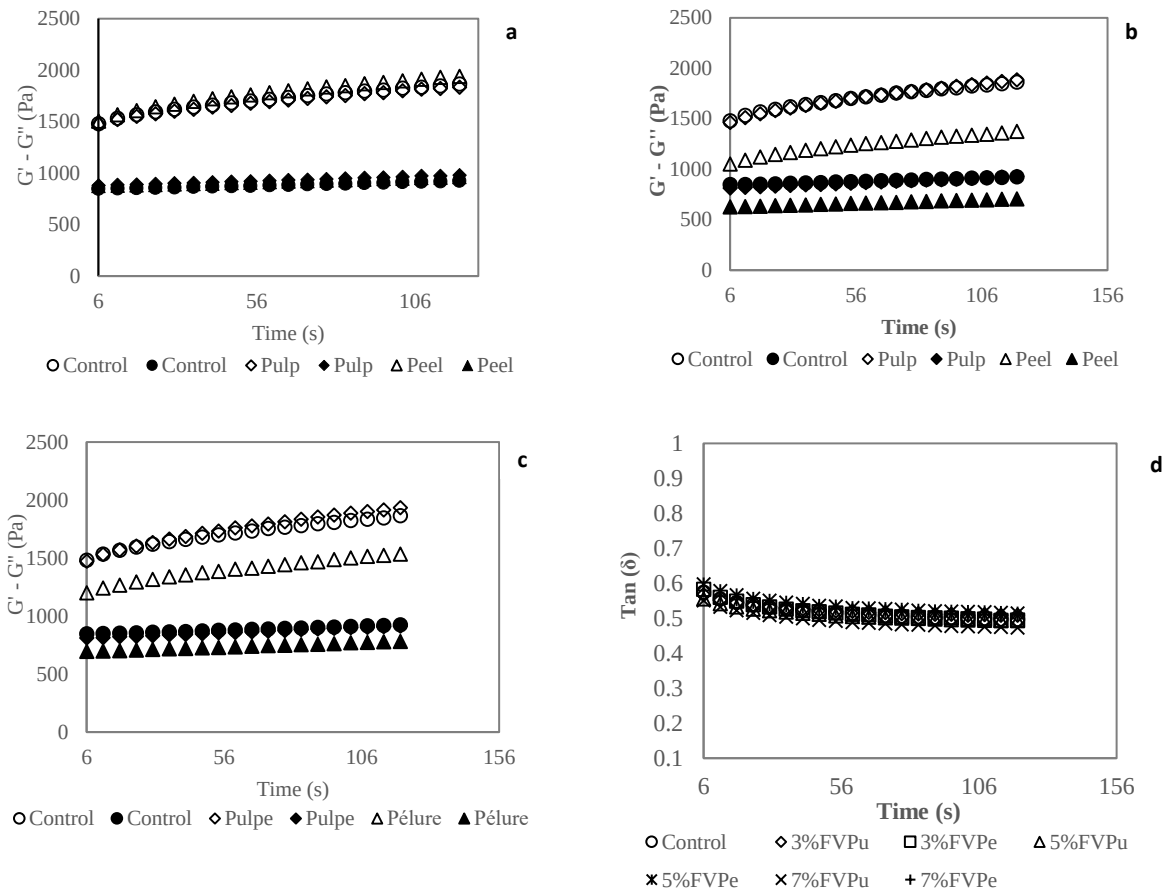


Figure 5: Viscoelastic behavior of cake batters

a, b and c: $G' - G''$ as a function of shear time for cake batters made with wheat flour containing black plum pulp flour (FVPu) or peel flour (FVPe) at 3, 5 and 7% incorporation levels, respectively. **d:** $\tan \delta$ as a function of shear time for cake batter samples shown in **a, b** and **c**. Open symbols refer to the storage modulus (G'), and closed symbols indicate the loss modulus (G'').

Conclusions

The powders did not induce any significant effects ($P > 0.05$) on the thermal properties of wheat flour, particularly the gelatinization temperature range ($T_c - T_i$) of the starch, and the viscoelastic characteristics of the dough. Black plum powders (pulp and peel) can be incorporated into wheat flour to enrich it with fibers without causing major changes to the thermal and rheological properties of the wheat dough. In the future, we plan to study the effect of black plum flour on the textural properties of the cake.

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Author Contributions

All authors contributed to the study conception, design and realization. Material preparation, data collection and analysis were performed by Koba Fatou Traoré and Kisselmina Youssouf Koné. The first draft of the manuscript was written by Koba Fatou Traoré and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Institutional Review Board Statement

The protocol carried out in this research did not involve the use of animals.

Informed Consent Statement

Not applicable.

Data Availability Statement

The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding authors.

Conflicts of Interest

The authors declare no conflicts of interest.

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