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Evaluation of particle size, flowability and thermal properties of formulated composite wheat-sologold sweet potato flour for baked products

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This paper attempts to formulate a composite wheat-sologold sweet potato flour that would have good texture, water absorption, dough rheology and heat transfer required for quality baked products. In this study, a completely randomized design was used to determine the best blend of composite flour, followed by the evaluation of its particle size, flowability and thermal properties. The results showed that a lower mean diameter of sologold sweet potato flour would enhance even distribution (mixing) with the wheat flour. Thus, having a thoroughly mixed composite flour with recommendable consistency, hydration rate, texture, flowability and heat transfer. The Carr index and Hausner ratio of the flour samples were within the range 5 to 15% and 1.0 to 1.1, respectively of flour that exhibits free-flowing properties. Furthermore, the range of the composite samples' moisture content was 11.90 to 9.60% db, bulk density 480 to 390 kg m^{-3}, specific heat capacity 2.10 to 1.95 KJ kg^{-1} K^{-1}, thermal conductivity 0.15 to 0.11 Wm^{-1} k^{-1}, and thermal diffusivity 0.09 to 0.06 m^{2} s^{-1}. These values further indicate that the developed composite flour has the potential to enhance efficient quality processing, stability, and safety of the baked products.

Key words: Particle size, flowability, thermal properties, wheat flour, sologold flour.

INTRODUCTION

Sologold sweet potato flour is a variety of orange sweet potato flour known for its rich nutritional profile, including high levels of dietary fiber, vitamins, and minerals. It is a promising ingredient for composite flour development (Oloniyo et al., 2021). Wheat flour plays a crucial role in baking by providing structure, texture, and flavor to baked products. It forms the foundation of bread, cakes, cookies, pastries, and other baked goods (Edema et al., 2005; Olaoye et al., 2006; Li et al., 2020). Moreover, the ever-increasing cost of wheat flour, its non-availability,

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and the lack of cheaper alternatives have been major constraints in the baking industry in Nigeria (Edema et al., 2005; Olaoye et al., 2006). Hence, the need for a nutritious, cheaper, and highly available alternative flour to wheat flour (Fabian and Nwamaka, 2016; Oloniyo et al., 2021).

The development and utilization of composite flour align with broader goals of food security, sustainable agriculture, and improved nutrition (Baljeet et al., 2014; Lee-Hoon et al., 2017; Selvakumaran et al., 2019). It can contribute to the diversification of food sources, utilization of agricultural by-products, and reduction of post-harvest losses (Santiago et al., 2015; Liu et al., 2020). Additionally, composite flour can promote the utilization of alternative protein sources, increase dietary diversity, and contribute to the well-being of populations, particularly in regions where food inaccessibility and malnutrition are prevalent (Larief and Dirpan, 2018; Curayag and Dizon, 2019). Composite flour production would thereby minimize the demand for imported wheat and help produce nutritious baked products; conserve foreign reserves and widen the utilization of indigenous crops in food formulation (Ade-Omowaye et al., 2008).

The composition and proportions of the different flours in a composite blend are typically determined through scientific evaluation, considering factors such as particle size, flowability, and thermal properties (Giami et al., 2004; Devani et al., 2016). The particle size distribution of wheat flour is an important quality that influences its functionality and performance. This is because varying particle sizes will affect the texture, structure, and processing characteristics of the final baked product (Wanjuu et al., 2018; Pycia and Ivanisova, 2020). Moreover, it influences the flowability, bulk density, and mixing behavior of the flour. Finer particles tend to have better water absorption and can contribute to improved dough rheology (Falola et al., 2013; Azni et al., 2018). The thermal properties of composite flour influence its behavior during the baking process. Understanding these properties is vital for optimizing processing conditions, ensuring uniform heat transfer, and controlling the formation of desirable texture and flavors in the final product (Krishnan et al., 2011; Menon et al., 2014).

Some of the factors that influence thermal properties are moisture content, bulk density, specific heat, and thermal diffusivity. The moisture content of wheat-sologold sweet potato flour must be carefully controlled to ensure that it falls within an acceptable range for proper processing and consumption. Too low moisture content may cause the flour to become dry and unpalatable (Aparecida Pereira et al., 2019). Excess moisture can lead to microbial growth and enzymatic reactions, causing deterioration and reducing the flour's overall quality. Bulk density plays a crucial role in determining the flowability and handling characteristics of the composite flour during processing, transportation, and packaging. Specific heat is a fundamental property that influences the heat transfer and energy required for baking food products. Understanding the specific heat of composite flour is crucial for designing an efficient baking process (Shimelis et al., 2006; Ulfa et al., 2019). Hence, determining appropriate baking times and temperatures, as well as designing energy-efficient drying methods during processing. Thermal conductivity is a key parameter for understanding how heat is transferred through the composite flour. It plays a significant role in determining the heat distribution and baking characteristics of baked products (Hanim et al., 2014; Chuango et al., 2019). It also influences the time required to achieve the desired texture, product quality, and impacts the product's stability during storage (Julianti et al., 2016; Chuango et al., 2019).

Flowability is the ability of a powder or flour material to flow freely and consistently. It is a key property that affects the processing of composite flour in various stages, such as mixing, transportation, and packaging (Healthy and Roida, 2019). Good flow properties prevent clogging or segregation of the components during mixing and ensure consistent flow in feeders or hoppers during industrial production, while poor flowability can lead to issues like clogging in equipment, uneven distribution of ingredients, and reduced production efficiency (Ajanaku et al., 2012a, b; Fabian and Nwamaka, 2016). Moreover, flowability influences the functional properties such as dough swelling power of the composite flour as well as the physical properties of the baked products (Ahmed and Hussein, 2014; Etti et al., 2019). Therefore, the aim of this study is to evaluate the particle size, flowability, and thermal properties of the developed composite wheat-sologold sweet potato flour to ensure its suitability for bakery products.

MATERIALS AND METHODS

Material sourcing and equipment

The materials used for this study includes sologold sweet potatoes, which was collected in Nigeria from National Root Crops Research Institute Umudike, Abia State and quality wheat flour (Dangote brand). The equipment used for this study includes hammer mill, mechanical sieves, electronic weighing balance, stop watch, electronic dough mixer, electronic PH meter, desiccators, stirrer, volumetric flasks, pipettes, beakers, crucibles, bowls, Soxhlet apparatus, digestion flask, rapid visco-analyzer, ultraviolet/infrared and spectrophotometer. The automatic sieve shaker, flour calorimeter, and exploded view of the flour calorimeter are as shown in Figure 1a, b and c, respectively.

Production of composite wheat-sologold sweet potato flour

The study design used was completely randomized design (CRD) with A1= Wheat flour (100%), SSPF (0%); B1= Wheat flour (90%), SSPF (10%); B2= Wheat flour (80%), SSPF (20%); B3= Wheat flour (70%), SSPF (30%); B4= Wheat flour (60%), SSPF (40%), and B5= Wheat flour (50%), SSPF (50%) shown in Table 1.

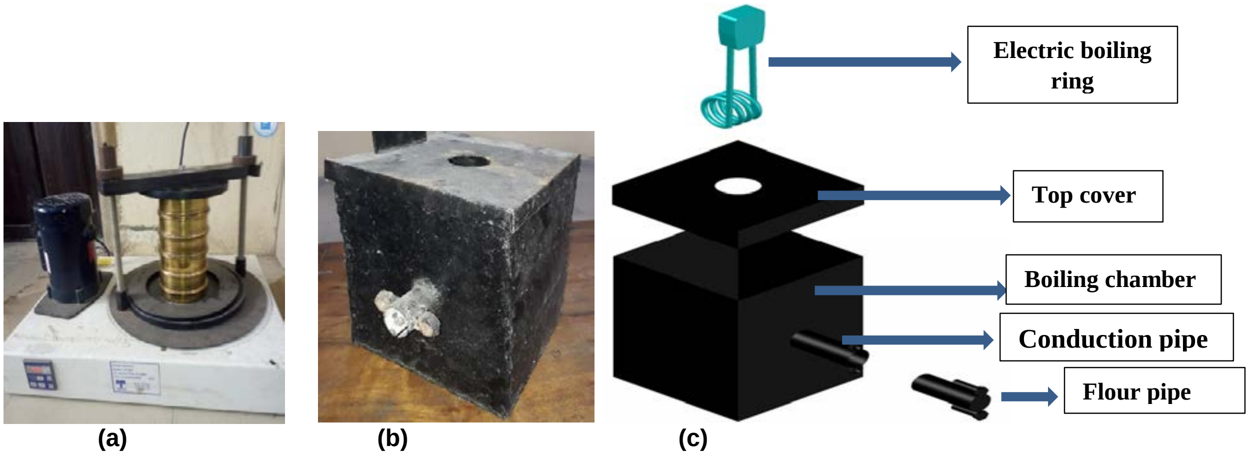

Figure 1. (a) Automatic sieve shaker; (b) Flour calorimeter; (c) Exploded view of the flour calorimeter.

Table 1. Wheat-sologold sweet potato flour formulation.

Sample	Flour blend ratio	SSPF (g)	WF (g)
A1	100% WF, 0% SSPF	0	300
B1	90% WF, 10% SSPF	30	270
B2	80% WF, 20% SSPF	60	240
B3	70% WF, 30% SSPF	90	210
B4	60% WF, 40% SSPF	120	180
B5	50% WF, 50% SSPF	150	150
B6	40% WF, 60% SSPF	180	120
B7	30% WF, 70% SSPF	210	90
B8	20% WF, 80% SSPF	240	60
B9	10% WF, 90% SSPF	270	30
A2	0% WF, 100% SSPF	300	0

SSPF= Orange fleshed sweet potato flour; WF= Wheat flour.

Determination of particle size analysis of wheat-sologold sweet potato flour

The particle size distribution of flour samples obtained from the blends of wheat and sologold flour was carried out using technique as described by Lesego (2014). Different sieves with varying aperture sizes (10, 22, 44, 60 and 150 μm) were arranged on top of each other with the one having the biggest aperture on the topmost level and then arranged in decreasing order. The sieves were fastened into a rigid position using a fastening screw after a standard quantity of the flour sample (50 g) already placed inside the topmost sieve. The sieve was shaken for 8, 10, 12, 14, 16 and 18 min after which the quantity of flour retained on each sieve was collected, weighed and calculated as Equation 1:

$$\% \text{ Recovered} = W_{sieve} / W_{total} \times 100 \qquad (1)$$

where W_{sieve} is the weight of the aggregate in the sieve, W_{total} is the weight of the total aggregate. The methodology used for the particle size analysis was prescribed by Niu et al. (2019). The test sieves 'nest' were assembled together to form a 'stack' of sieves with the test sieve shaker providing both circular and tapping energy coupled with uniform mechanical motion for good consistent result. Since the flour particles are free flowing it requires less time than bulky particles. Hence, 10 to 15 min time period is sufficient for performing the test. The test was carried out as per ASTM D44 using standard sieve analyzer. A representative weighed sample was poured into the top sieve which has the largest screen openings of 1.8 mm. Each lower sieve in the column has smaller openings than the one above. At the base is a round pan, called the receiver. The column is typically placed in a mechanical shaker. The shaker shakes the column usually for 15 to 20 min. After the shaking is complete, the material on each sieve is weighed. The weight of each sample is then divided by total weight to give a percentage retained on each sieve. The size of the average particles on each sieve was analysed to get the cut point or specific size range captured on screen. To find the percent of aggregate passing through each sieve, first find the percent retained in each sieve. To do so, the Equation 2 used is given as:

$$\% \text{ Retained} = W_{sieve} / W_{total} \times 100 \qquad (2)$$

where W_{sieve} is the weight aggregate in the sieve and W_{total} is the total weight of the aggregate. The next step is to find the cumulative percent of aggregate retained in each sieve. To do so, add up the total amount of aggregate that is retained in each sieve and the amount in the previous sieves. The cumulative percent passing of the aggregate was found by subtracting the percent retained from 100%; and is given as Equation 3:

$$\% \text{ Cumulative passing} = 100\% - \% \text{ cumulative retained} \qquad (3)$$

The formula for average particle diameter (Dav) is given as Equation 4:

$$Dav = \sum_{n} \times d \,/\, {}_{n}\sum (u/m) \qquad (4)$$

where m is the mass of the flour sample, u is the aperture size, n is the number of apertures, and d is the particle diameter.

Flowability of wheat-sologold sweet potato composite flour

The flowability of the composite flour were determined using American Association of Analytical Chemists (AOAC, 2016) methods. In order to characterize the flowability of the composite flour samples, the bulk density, angle of repose, hausner ratio and carr index were employed. Bulk density (*pb*) can be identified as the ratio of the weight of powder (flour) in a vessel to the volume occupied in the vessel before tapping. Whereas tap density is a different type of bulk density obtained by tapping or vibrating the container in a particular pattern. Therefore, it is usually higher than bulk density (*pb*), and is given as Equation 5:

$$pb = \frac{Wt}{Vb} \qquad (5)$$

where Wt is the weight of the powder; and Vb is the volume of the powder obtained from tarred graduated cylinder without tapping. The tapped density (*p*tap) of the powders was calculated by using the following Equation 6:

$$p\text{tab} = \frac{Wt}{Vtap} \qquad (6)$$

where Wt is the weight of powder and $Vtap$ is the volume of the powder bed after 500 taps. Carr index and Hausner ratio can be used in describing the flow indexes and flowability of powder. Carr index (*CI*) can be determined as the ratio of the difference of the tapped density (*p*tab). An excellent flowability is between the Carr index of 5 and 15% while Carr index of above 25% normally shows poor flowability. The Carr index (CI) could be expressed as (Equation 7):

$$CI = \frac{\rho tap - \rho b}{\rho tap} \qquad (7)$$

Hausner Ratio (HR) was also used to characterize the flowability of the powder, which can be determined by the ratio of the tapped density to that of bulk density. HR between 1.0 and 1.10 shows a powder that is free-flowing, HR between 1.11 and 1.25 shows a powder that is considered to be medium flowing. When the HR is between 1.26 and 1.4, the powder is considered to be difficult to flow, and for HR greater than 1.4, the powder is considered to be very difficult to flow. Angle of repose is the same as angle of internal friction under the loosest packing condition. The measurement of angle of repose (ϴr) was done using a static and loose base piling method. The bottom stem of a funnel was positioned 6 cm above a horizontal. The measurement of the angle between the heaps with respect to the horizontal using the protractor was taken as the angle of repose. The experiment was done in triplicate for each flour and the average value recorded. The Θ_R may be written as Equation 8 (Etti et al., 2019):

$$\Theta_R = \tan^{-1} \frac{2H}{D} \qquad (8)$$

where Θ_R = Angle of repose (^{0}), H = Height of the pile (m), and D= Diameter of the pile (m).

Determination of thermal properties of wheat-sologold sweet potato composite flour

The thermal properties were determined using American Association of Analytical Chemists (AOAC, 2016) method. These include thermal conductivity, heat capacity and thermal diffusivity. The direct thermal measurement was employed, which consist of measuring the temperature rise and the time evaluation of an electrically heated pipe embedded in the sample flour. The thermal conductivity is derived from the resulting change in temperature over a known time interval (Basman and Koksel, 2003; Begum et al., 2013). The ideal analytical model assumes an ideal-infinitely thin and infinitely long line heat source, operating in an infinite, homogenous and isotropic material with uniform initial temperature. If the hot pipe is heated for the time $t = 0$ with the constant heat flux q per unit pipe length, the radial heat flow around the pipe will occur. The thermal conductivity is calculated from the slope S of the temperature rise. However, several modifications have been made to account for the heat capacity of the pipe, the thermal resistance between the pipe and the sample, the finite dimension of the sample and the finite dimension of the pipe embedded in the sample. The hot pipe method is in accordance with the measurement of the temperature increase, and the place of the temperature sensor. Heat transport takes place in three ways: conduction, convection, and radiation. Heat transport in flour mass is performed by the conduction and by convection of air occurring between the flour depending on the method of storage. The following are thermal properties expressions:

(i) The heat capacity Cp is given as Equation 10:

$$Cp = CwWw\,(Te - Tw) - CcaWca\,(Tca - Te) \,/\, Ws\,(Ts - Te) \qquad (10)$$

where Cp = specific heat of the sample (KJ/Kgk), Cw = specific heat of water (KJ/Kgk), Cca = specific heat of the capsule (KJ/Kgk), Ww = weight of water in the calorimeter (kg), Wca = weight of the capsule (kg), Ws = mass of the sample (kg), Tca = initial temperature of the capsule containing the sample (K), Te = equilibrium temperature of the mixture (K), Tw = initial temperature of water in the calorimeter (K), and Ts = initial temperature of the sample (K).

(ii) Thermal conductivity (K) is given as Equation 11:

$$K = VI \ln (t2/t1) \,/\, 4\pi l\,(T2 - T1) \qquad (11)$$

where K= Thermal conductivity, V= Voltage (v), I= Current, t1= Initial time (s), t2= Final time (s), π = Pie, T1= Initial temperature (°C), and T2= Final temperature (°C).

(iii) Thermal diffusivity (α) is given as Equation 12:

$$\alpha = h \,/\, c\, p \qquad (12)$$

where α = thermal conductivity, h = thermal conductivity, *c* = specific heat, and *p* = bulk density.

RESULTS AND DISCUSSION

Production of composite wheat-sologold sweet potato flour

Leveraging on the distinct qualities and characteristics of

Table 2. Arithmetic mean diameter and percent finer of wheat flour and SSP flour.

Dav (% finer)					
8 min	**10 min**	**12 min**	**14 min**	**16 min**	**18 min**
Wheat flour					
393.42 (96)	414.23 (98)	347.77 (98)	434.82 (96)	414.28 (96)	462.42 (96)
SSP flour					
412.88 (90)	354.13 (96)	374.67 (94)	366.82 (94)	294.75 (96)	308.55 (96)

each flour to produce a composite flour is achieved by formulation (blending different ratios) of the flours. Hence, evaluation of the flour parameters such as the particle size, flowability and thermal property is needed to select the best blend.

Particle size analysis of wheat-sologold sweet potato flour (SSPF)

The arithmetic mean diameter and percent finer of wheat flour and SSPF as influenced by sieving time is shown in Table 2. The effect of sieving time on the mean particle size of wheat flour and SSP flour show that the lowest wheat flour mean diameter was 347.77 at 12 min with percent finer of 98% and the highest mean diameter was 462.42 at 18 min with percent finer of 96% while the lowest sologold sweet potato flour mean diameter was 294.75 at 16 min with percent finer of 96% and highest mean diameter was 412.88 at 8 min with percent finer of 90%. The lower mean diameter of sologold sweet potato flour will enhance an even distribution (mixing) with the wheat flour; thus having a thoroughly mixed composite flour with recommendable flour's consistency, hydration rate, texture, flowability and bulk density (Bibiana et al., 2014; Chuango et al., 2019). Finer particles tend to have better water absorption and can contribute to improved dough rheology (Phomkaivon et al., 2018; Ulfa et al., 2019; Julianti et al., 2019). The optimum blend of the composite flour sample blended and mixed well with good texture and flour consistency.

Flowability of the wheat flour, sologold sweet potato flour and composite flour samples

The flowability behaviour of the samples were determined by characteristics such as bulk density, tapped density, angle of repose, carr index and hausner ratio shown in Table 3. The results for the angle of repose shown in Table 3 have all the flour samples having angle of repose of not more than 32.5°. These results confirmed that all the composite flour samples fall under the free flowing classification (Etti et al., 2019). The flowability behaviour of the composite flour samples was determined using the flour densities (tapped density and bulk density) to further calculate for the percentage Carr index and Hausner ratio for the composite flour samples. The range of Carr index obtained was between 11.0 and 4.0% *CL* and Hausner ratio was 1.10 to 1.04 *HR* indicating good flowability. This is because the flowability index of flour (powder) is known to have excellent flowability if the *CL* is between 5 and 15% while *CL* above 25% is considered poor flowability. Also, flour is considered as free flowing if the *HR* is between 1.0 and 1.1 and if the *HR* is greater than 1.25 to 1.4, the powder is classified as difficult to flow and if the *HR* is higher than 1.4, the flour is considered to be very difficult to flow (Etti et al., 2019). The density of the composite flour samples was observed to decrease as the mix ratio of the sologold sweet potato flour increased. This suggests that sologold sweet potato flour has lesser density than the wheat flour. Therefore, the flow index of all the composite flour samples showed excellent free flowing behavior (Adebowale et al., 2005; Niu et al., 2019). Hence, optimum blend composite flour is recommended for the production of good quality baked products.

Thermal properties of composite wheat-sologold flour

The thermal properties considered were specific heat, thermal conductivity and thermal diffusivity. Table 4 shows the thermal properties of composite flour samples as affected by moisture content and bulk density. The composite wheat-sologold sweet potato flour samples exhibit unique thermal properties compared to individual flours. This affects the baking time, heat distribution and development of desirable textures and flavours in the end product (Masood et al., 2011; Martín-Esparza et al., 2013). The range of the specific heat of the composite flour samples was 2.10 to 1.95 KJK^{-1} g K^{-1} with B3 having the highest while B5 had the lowest since high specific heat aids in determining the amount of heat required and the time needed for baking the composite dough to a specific moisture content, ensuring energy efficiency and minimizing processing time the B3 composite is recommended (Omoba et al., 2013; Aziz et al., 2018; Azzahra et al., 2019). The range of the thermal

Table 3. Flowability of wheat flour, SSP flour and composite flour samples.

Sample	W:SSP (g)	Bulk Density (kg/m^3)	Tapped Density (kg/m^3)	Angle of Repose ~~O~~R	Carr Index CL%	Hausner Ratio HR	Flowability behaviour
A1	100:0	500±4.5^{a}	530±4.2^{b}	34.0±2.5^{a}	09	1.06	Free flowing
B1	90:10	480±4.0^{b}	512±4.6^{b}	32.5±2.0^{a}	11	1.07	Free flowing
B2	80:20	460±4.6^{bc}	495±4.2^{b}	31.5±2.2^{a}	07	1.07	Free flowing
B3	70:30	450±3.6^{bc}	480±4.5^{b}	30.0±1.0^{a}	06	1.06	Free flowing
B4	60:40	440±2.5^{bc}	465±4.0^{c}	28.5±2.0^{ab}	05	1.05	Free flowing
B5	50:50	430±3.2^{bc}	450±3.5^{c}	28.0±1.0^{ab}	04	1.04	Free flowing
B6	40:60	420±4.0^{c}	440±4.6^{c}	27.0±1.5^{ab}	04	1.05	Free flowing
B7	30:70	410±3.5^{c}	432±4.0^{c}	26.0±0.5^{b}	11	1.05	Free flowing
B8	20:80	400±2.8^{c}	425±3.5^{a}	25.4±1.2^{b}	10	1.06	Free flowing
B9	10:90	390±2.5^{c}	430±3.0^{a}	24.5±2.0^{b}	09	1.10	Free flowing
A2	0:100	380±3.0^{c}	415±2.5^{a}	23.0±1.0^{b}	08	1.09	Free flowing

Value followed by same superscript alphabet are not significantly different at ($P<0.05$) along the column. Values are Mean ± SEM of triplicate determination.

Table 4. Thermal properties of composite wheat-sologold flour as affected by moisture content.

Sample	Moisture content (%db)	Bulk density (kg m^{-3})	Specific heat (KJKg^{-1}K^{-1})	Thermal conductivity (Wm^{-1}K^{-1})	Thermal diffusivity (m^{2}s^{-1})
A1	12.02±0.8^{c}	500±4.5^{a}	1.90	0.15	0.10
B1	11.90±1.0^{c}	480±4.0^{b}	2.05	0.15	0.09
B2	11.86±1.5^{c}	460±4.6^{c}	2.07	0.14	0.09
B3	11.14±1.4^{c}	450±3.6^{c}	2.10	0.14	0.08
B4	10.54±1.2^{c}	440±2.5^{c}	2.09	0.14	0.08
B5	10.35±1.5^{c}	430±3.2^{c}	1.95	0.13	0.08
B6	10.12±1.6^{c}	420±4.0^{c}	2.08	0.13	0.07
B7	9.83±0.5b^{c}	410±3.5^{c}	2.02	0.12	0.07
B8	9.74±1.0b^{c}	400±2.8^{c}	2.04	0.12	0.07
B9	9.60±1.2b^{c}	390±2.5^{c}	2.01	0.11	0.06
A2	9.52±0.8b^{c}	380±3.0^{c}	2.06	0.10	0.05

The alphabets a, b, c on any value in the same column means there is no significant different at ($P < 0.05$) between the values. Values are Mean ± SEM of triplicate determination.

conductivity of the composite flour samples was 0.15 to 0.11 Wm^{-1}k^{-1} with B1 having the highest, while B9 had the lowest. These values confirm even distribution of heat throughout the composite flour and will result in consistent product quality and desirable product characteristics (Ulfa et al., 2019). The range of the thermal diffusivity of the composite flour samples was 0.09 to 0.06 m^{2}s^{-1} with B1 and B2 having the highest, while B9 had the lowest. These values could encourage predicting and controlling the temperature distribution within the material during processing (Chuango et al., 2019). However, thermal property could be influenced by moisture content (Krishnan et al., 2011; Low et al., 2017).

Therefore, the moisture content of wheat-sologold sweet potato flour must be carefully controlled to ensure that it falls within acceptable ranges for safe storage and consumption. The moisture content range for the composite flour samples was 11.90 to 9.60% db, with B1 having the highest and B9 the lowest. This range is moderate and acceptable. Usually, excessively high moisture content can lead to microbial proliferation, while too low moisture content may cause the product to become dry and unpalatable (Adebowale et al., 2005; Pycia and Ivanisova, 2020).

The bulk density range for the composite flour samples was 480 to 390 Kgm^{-3}, with B1 having the highest and B9 the lowest. However, B3 was chosen as having a suitable bulk density for composite wheat-sologold sweet potato flour, ensuring that it occupies a reasonable volume and minimizes storage space and transportation expenses. Generally, an increase in moisture content reflects an increase in thermal conductivity and thermal diffusivity.

Table 5. ANOVA of the Thermal Properties of composite wheat-sologold flour.

Composition		Sum of squares	Df.	Mean square	F	Sig.
MC	Between groups	102.82346	3	1.52846	2.34812	1.072
	Within groups	0.014	1	0.004		
	Total		4			
BD	Between groups	220.9374	20	5.82744	5.06271	1.091
	Within groups	0.032	1	0.003		
	Total		21			
SH	Between groups	2.8402	2	0.01371	1.65828	0.320
	Within groups	0.010	1	0.002		
	Total		3			
TC	Between groups	2.7721	3	0.02193	1.29374	0.708
	Within groups	1.21	1	0.003		
	Total		4			
TD	Between groups	1.2216	1	0.048441	2.18032	0.214
	Within groups	0.25	2	0.002		
	Total		3			

MC: Moisture content, BD: Bulk density, SH: Specific heat, TC: Thermal conductivity, TD: Thermal diffusivity.

Thermal conductivity of the samples ranged from 0.15 to 0.10, while thermal diffusivity ranged from 0.10 to 0.05. The values obtained showed low thermal conductivity and diffusivity, suggesting effective heat transfer in the composite flour samples (Healthy and Roida, 2010; Wanjuu et al., 2018; Julianti et al., 2019). Table 5 presents the ANOVA for the thermal properties. The ANOVA results (Table 5) show that there is no significant difference ($p > 0.05$) in the thermal properties of the composite flour samples.

Conclusion

The evaluation of composite wheat-sologold sweet potato flour samples showed that a lower mean diameter of sologold sweet potato flour will enhance even distribution with the wheat flour, resulting in a thoroughly mixed composite flour with recommendable consistency. The Carr index and Hausner ratio of the flour samples were within the range indicative of flour that exhibits free-flowing properties. Among the composite wheat-sologold sweet potato flour samples, B3 (70:30) is recommended as the optimum blend for efficient quality processing, stability, and safety of baked products based on the evaluation of particle size, flowability, and thermal properties.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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