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Thermo-physical properties of composite bread dough with maize and cassava flours

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Summary Composite wheat–cassava and wheat–maize flours were produced in ratio 100:0. 60:40, 50:50, 40:60 and 0:100 respectively. Thermo-physical properties of bread dough were determined. For wheat –cassava composite bread dough, moisture content ranged between 44.02 ± 2.04 to 51.31 ± 2.99% dry basis (db), density (1035.2 ± 20.4 to 975.6 ± 12.6 kg m^{-3}), specific heat capacity (2.51 ± 0.61 to 3.01 ± 0.42 kJ kg^{-1} K) and thermal conductivity (0.362 ± 0.13 to 0.473 ± 0.12 W mK^{-1}). While wheat–maize mixture gave 44.14 ± 1.94 to 45.09 ± 1.26%(db) of moisture content, 981.4 ± 16.3–960.4 ± 22.5 kg m^{-3} density, 1.77 ± 0.17–2.61 ± 0.63 kJ kg^{-1} K specific heat capacity and 0.36 ± 0.07–0.39 ± 0.02 W mK^{-1} thermal conductivity. Effects of substitutions was significant on moisture content and thermal conductivity of dough while non significant influence was recorded on density and specific heat capacity at $P < 0.05$.

Keywords Bread dough, cassava flour, composite flours, density, heat capacity, heat penetration, maize flour, moisture content, thermal conductivity, wheat flour.

Introduction

In the baking industry, there has been an increasing trend in the usage of non–wheat flours in the manufacture of baked goods such as bread, cake, biscuit, snacks, pasta products and other confectioneries. Such products, that have found acceptability worldwide, are used to increase protein intake especially in developing countries (Satin, 1988). Minerals contents and dietary fibre of baked products can be enhanced by composite flours (Karina de Simas *et al*., 2009), The peculiar properties of wheat flour which make it indispensable for the preparation of light, well aerated food such as bread, is the ability of its proteins (gluten) to form very thin continuous films and fibrils that can stretch and retain gas bubbles produced during fermentation (Brown, 2002). This properties exhibited by wheat proteins, is lacking in other cereal proteins, which do not form fibrils when hydrated. However, there is much improvement when a gel-forming substance, such as starch is added. The enormous potential for industrial utilisation of non–wheat cereal, roots and tubers and legumes in bread making is attracting research attention in Nigeria. Bread making involves the transformation of mixed dough, by application of heat, into a light, porous, readily digestible and flavourful product. It is a heat and mass transfer operation that involves a series of complex temperature dependent chemical, physical and thermal reactions (Johnsson & Skjoldebrand, 1987). This ranges from dough softening to starch gelatinisation, up to browning and dextrinisation.

Thermo-physical properties of food products were reported to be function of their composition. Studies have been carried out on some thermo- physical properties of foods such as milk (Riedel, 1949), starch (Reidy, 1968), rape seed (Moysey *et al*., 1977), apple (Mohsenin, 1980), soybean flour (Wallapapan & Sweat, 1982), bread (Johnsson & Skjoldebrand, 1987), hydrated cowpea (Taiwo *et al*., 1996), palm kernel (Obetta, 2000), rice (Ramesh, 2000), fig fruit (Basavaraj *et al*., 2008) and cassava (Ademiluyi *et al*., 2008). However, there is dearth of information on the thermal properties of composite bread dough, which is the new trend of bread making technology in Nigeria. Knowledge of the thermo-physical properties of composite bread dough is essential in its formulation and accurate engineering designs of processing equipment. According to Mohsenin (1980), mechanical action required during dough formation can affect some physical properties. A foreknowledge of the specific heat capacity and thermal

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conductivity of dough would serve useful in predicting the quantity of heat to be transferred into a known mass of dough during baking (Matz, 1997). Influence of moisture on dynamic rehological properties of cassava dough was significant according to Rodríguez–Sandoval *et al.* (2009). Density of the dough is related to final loaf volume, which is one of the consumers' indices for purchasing bread. Hence, both physical and thermal properties can be used in assessing the quality of composite and wheat less dough.

The objective of this study was to determine the density, moisture content, specific heat capacity and thermal conductivity of composite bread dough produced from wheat–cassava and wheat–maize flours. To ensure bread of high quality by this technology of composite and wheat-less bread manufacture, the thermo-physical properties of their dough should be established.

Materials and methods

Materials

Commercial whole-wheat and maize flours (Golden penny, Flour Mills of Nigeria PLC, Lagos, Nigeria) were procured from Flour Mills of Nigeria PLC Lagos, Nigeria. TMS-50395 cassava tuber was sourced from International Institute of Tropical Agriculture (IITA, Nigeria). Freshly harvested cassava tuber were washed and peeled manually. Peeled tubers were milled using hammer mill (model FE 326B, FOBA Engineering, Nigeria). The mash was anaerobically fermented in a non- corrosive container for 2 h. From zero hour to the end of the period, the mash was intermittently and vigorously stirred to ensure intimate contact of endogenous enzymes with the substrate. Immediately after the fermentation period, the mash was dewatered using hydraulic press. Resultant product is termed cake, which was mechanically size-reduced to produce fine granules. Then, these granules were dehydrated using rotary hot-air dryer at 60 °C for 12 h. Dried product was milled and sieved to produce fine powder. Fineness modules of flour samples were determined using a set of eight Endicott test sieves ranging from 600 μm to 53 μm sieve sizes arranged in decreasing order of pore size. Cumulative graphs and histograms were drawn to obtain the average particle size and the most common particle size of each flour sample.

Sample preparation

The whole-wheat flour was substituted separately with cassava and maize flours of 0%, 40%, 50%, 60% and 100% of its initial weight. Thus, the composite wheat–cassava and wheat–maize flours were produced in ratio 100:0. 60:40, 50:50, 40:60 and 0:100 respectively. Using the prepared composite flours, trial experiments were carried out to ensure ascertains appropriate measure of the ingredients. Bread dough for the research work was produced using the ingredients on Table 1. The ingredients were mixed for 5 min in Brabender Farinograph mixer rotating at 31.3 rpm. This was followed by a rest period of about 15 min in order to relive residual stresses that occurred during mixing. The dough was moulded into cylindrical shape to fit into a 0.2-mm thick aluminium container (internal diameter of 20 mm and height of 200 mm). Dough height was made up to a specified ring mark, with adequate allowance for dough swelling during baking. The dough were prepared, proved in baking pans at 38 °C and 85% relative humidity for 40 min and then introduced centrally into baking oven.

Physical properties

Moisture content was determined by drying 5 g of sample for 6 h in a Carter–Simon oven set at 130 °C. Moisture content in percentage dry basis was calculated as ratio of moisture to weight of dried sample. The displacement method of glycerin was employed in density measurement. Five grammes of dough, were lowered into a known volume of glycerin in a measuring cylinder. The change in volume was noted and density was calculated as mass per unit volume.

Thermal properties

Specific heat of the samples was determined by method of mixture. This involved dropping the dough of known mass and temperature into fluid (glycerin) of known mass and temperature contained in a calorimeter (model 6300EA; Preiser Scientific, Louisville, KY, USA). Changes in temperature(s) of both the dough and glycerin were noted at 1 min interval until the temperature equilibrated after 6 min. Using First Law of

Table 1 Ingredients used for dough preparation

Ingredient	W	C	M	WC^1	WC^2	WC^3	WM^1	WM^2	WM^3
Flour (g)*	100	100	100	100	100	100	100	100	100
Water (cm^3)‡	58	96	118	67	70	72	64	65	67
Sugar (g)†	10	10	10	10	10	10	10	10	10
Salt (g) †	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Yeast (g)†	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Oil/fat (cm^3)‡	2	2	2	2	2	2	2	2	2

*Accuracy of measurement is 2.0 g.

†Accuracy of measurement is 0.1 cm^3.

‡Accuracy of measurement is 0.05 g.

W, % wheat; C, % Cassava; M, % Maize. WC^1, wheat–cassava (40% substitution); WC^2, wheat–cassava (50% substitution); WC^3, wheat–cassava (60% substitution); WM^1, wheat–maize (40% substitution); WM^2, wheat–maize (50% substitution); WM^3, wheat–maize (60% substitution).

Thermodynamics (heat lost by the material equal to heat gained by the fluid and the calorimeter), the specific heat capacities of the dough were calculated using eqns 1 and 2 (McCabe *et al.*, 2005):

$$m_\mathrm{d}c_\mathrm{d}(T_\mathrm{d}-T_\mathrm{m}) = m_\mathrm{g}c_\mathrm{g}(T_\mathrm{m}-T_\mathrm{g}) + m_\mathrm{c}c_\mathrm{c}(T_\mathrm{m}-T_\mathrm{g}) \quad (1)$$

$$c_\mathrm{d} = \frac{(T_\mathrm{m}-T_\mathrm{g})(m_\mathrm{c}c_\mathrm{g}+m_\mathrm{c}c_\mathrm{c})}{(T_\mathrm{d}-T_\mathrm{m})m_\mathrm{d}} \quad (2)$$

where m_d is the mass of dough (kg), m_c the mass of calorimeter (kg), c_d the specific heat capacity of dough (kJ kg^{-1} K), T_d the initial temperature of dough (K), T_m the temperature of mixture at equilibrium (K), m_g the mass of glycerine (kg), c_g the specific heat capacity of glycerine (kJ kg^{-1} K), T_g the initial temperature of glycerine (K), c_c the specific heat capacity of calorimeter (kJ kg^{-1} K).

Thermal conductivities of the dough were determined by the transit heat flow method, using a thermal conductivity probe (Mohsenin, 1980). Experimental set-up consisted of a thermal conductivity probe (Lambda LM; PSL Systemtechnik, Clausthal-Zellerfeld, Germany), a potentiometer, a rheostat, a DC power supply (12 V, 0.5 A). The probe was inserted inside the core of the samples, and temperature was noted at an interval of 5 s. Time vs. temperature curve was plotted. Thermal conductivity (*K*) by eqn 3:

$$K = \frac{Q}{4\pi S} \quad (3)$$

where *K* is the thermal conductivity of dough (W mK^{-1}), *Q* the power supplied per meter length of probe W m^{-1} and *S* the slope of the time–temperature curve.

The change in temperature with time during the period of heating of dough was obtained from heat penetration experiments (Johnsson & Skjoldebrand, 1987). Three digital clamp multimeter (Mastech 266C; Probe Master, CA, USA) were used as probes at different radii, but at same axial distance were inserted into the dough. These were protected from excessive oven heat using a metal shield packed with glass wool as thermal insulation. This set-up system was introduced into the oven through an opening above the oven chamber after it had attained and maintained baking temperature (about 165 °C) for 45 min. A six-point Ellab temperature recorder, registered temperatures at 5 min interval. In this instance, heat transfer in the bread by conduction was unsteady. Thus, equation for one-dimensional heat flow with constant surface temperature is applicable (eqn 4):

$$\frac{\partial T}{\partial t} = \frac{k\partial^2 T}{\ell c_\mathrm{d}\partial x^2} \quad (4)$$

Where ∂T is the change in temperature (K), ∂t the time interval dough (s), ∂x the thickness of dough (mm) and ℓ the density of kg m^{-3}.

Statistical analysis

Three replicates each of the determination of flours particle size, moisture content, density, specific heat capacity and thermal conductivity of dough were carried out. Mean values were recorded as obtained data. Degree of influence on substitutions was determined by statistical analysis of obtained data from the experiments. For wheat–cassava composites, one-factor experiment with five levels of substitution factorial experimental design was employed while one factor experiment with four levels of substitution was used for wheat–maize composites dough. That is five and four levels of substitution for wheat–cassava and wheat–maize flours respectively for one level each of studied properties (moisture content, density, specific heat capacity and thermal conductivity). ANOVA and regression analysis of the results were carried out using SPSS 13.0 software package. Obtained values of moisture content, density, specific heat capacity and thermal conductivity were separately input as dependent variables while 0%, 40%, 50%, 60% and 100% levels of substitution were input as independent variables. Interaction between the variables was examined under linear and second order polynomial to establish appropriate mathematical relationship. Models were developed and effect of the substitution was considered at 5% level of significance.

Results and discussion

Physical properties

Particle size distribution curves of flour samples are shown in Fig. 1. The mean particle sizes were calculated to be 154, 228 and 330 μm while the most frequently occurring particle sizes determined from relative distribution histograms were 128, 256 and 256 μm for wheat, cassava and maize flours in respective order. The substitution of cassava flour with wheat flour produced bread dough at 0%, 40%, 50%, 60% and 100% cassava flour, however maize flour only form bread dough at 0%, 40%, 50% and 60%. Bread dough was not possible at 100% maize flour. This may be traced to low degree of fineness of maize flour (330 μm), which is comparatively big. The behaviour may also be linked with protein content (gluten) of hydrated maize flour, which was reported by Oladunmoye *et al.* (2004a) as hindrance to its visco-elastic properties.

Moisture content of the dough varied proportional with levels of substitution of the flours (Fig. 2). At the early stages of mixing, dough hydrates, taking water into protein structure and binding it by hydrogen bonding (UNECA, 1985). This accounts for variation in volumes of water required for dough making and the

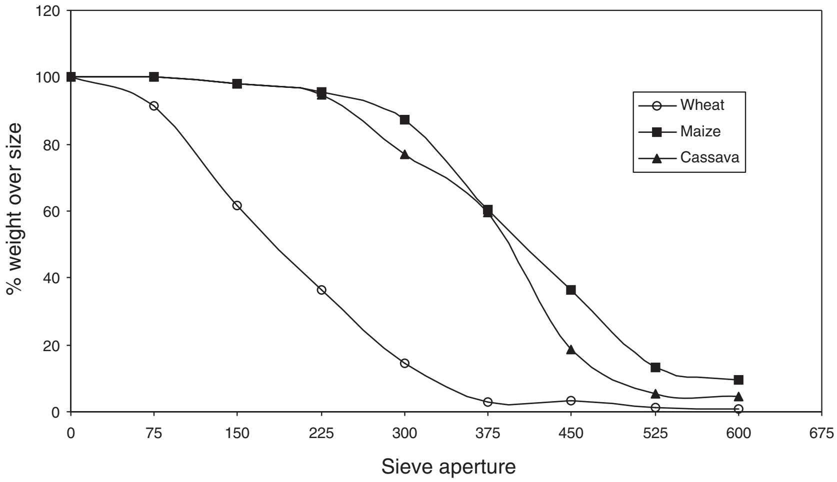

Figure 1 Particle size distribution of the flours.

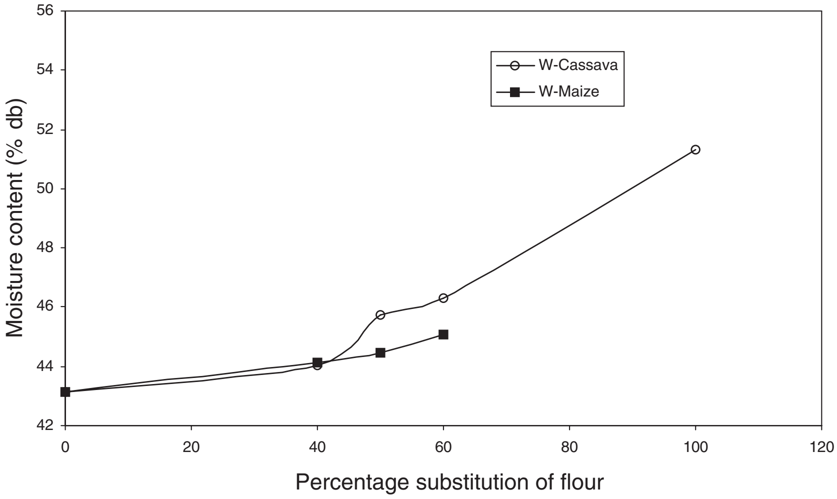

Figure 2 Moisture content of composite bread dough as influenced by proportional composition.

resultant moisture content of the dough. From the regression analysis of the results, high coefficient of determination R^2 (0.802) and (0.94) were obtained for wheat–cassava and wheat–maize composite dough respectively (Tables 2 and 3). An indication that the modes fit well and there is relationship between the parameters. Levels of substitution was also found to be significant at $P < 0.05$ for both wheat–cassava and wheat–maize dough. Moisture content of the dough was a function of the initial moisture content of the flour and quantity of water added for preparation.

Effects of cassava substitution were significant in a second order polynomial model for density, while at $P < 0.05$ non significant influence was recorded when wheat flour was substituted with maize flour. The densities of wheat–cassava composites dough were

Table 2 Summary of regression analysis of some properties of wheat–cassava composite dough

Properties	Models	Coefficients
Moisture content (%db)	MC = 40.719 + 0.125 WC	R^2 = 0.802 SE = 2.59
Density (kg m^{-3})	ρ = 1075.21–1.098 × 10^{-2}WC–0.974WC^2	R^2 = 0.979 SE = 15.82
Heat capacity (kJ kg K^{-1})	c_d = 2.69 + 6.15 × 10^{-5}WC–2.6910^{-5}WC^2	R^2 = 0.657 SE = 0.153
Thermal conductivity (kW mK^{-1})	k = 0.266 + 3.158 × 10^{-3}WC	R^2 = 0.879 SE = 0.048

WC, wheat–cassava; R^2, coefficient of determination; SE, coefficient of determination.

Table 3 Summary of regression analysis of some properties of wheat–maize composite dough

Properties	Models	Coefficients
Moisture content (%db)	MC = 43.071 + 3.036 × 10^{-2}WM	R^2 = 0.960 SE = 0.198
Density (kg m^{-3})	ρ = 1026.24 + 2.03 × 10^{-2}WM–2.792WM^2	R^2 = 0.517 SE = 50.84
Heat capacity (kJ kgK^{-1})	c_d = 2.653 + 3.66 × 10^{-4}WM–3.04 × $10^{-2}$$WM^2$	R^2 = 0.779 SE = 0.40
Thermal conductivity (kW mK^{-1})	k = 0.309 + 1.241 × 10^{-3}WM	R^2 = 0.962 SE = 0.001

WM, wheat–maize; R^2, coefficient of determination; SE, coefficient of determination.

higher with a range of 1035.2 ± 20.4 to 975.6 ± 12.6 kg m^{-3} (Fig. 3) than those of the corresponding wheat–maize composite dough (981.4 ± 16.3 to 960.4 ± 22.5 kg m^{-3}). The increased water content requirement in the cassava composite dough formulation probably accounts for this (Oladunmoye *et al.*, 2004a). Whole (100%) cassava bread dough, however, did not follow this trend, for it had a density of 1068 ± 19.89 kg m^{-3}. This observed difference could be attributed to the fact that hot water was added to (pre gelatinized) 16% of the cassava flour before mixing the 100% cassava bread dough (Satin, 1988). Hence the water (in the gelled dough) was not as free as in the case of 40%, 50% and 60% wheat substitution levels for composites. Similar reports were obtained on bread made from pre gellatinised maize flour (Akobundun *et al.*, 1988). With increasing substitution with maize flour however, density decreased, despite slight increase in volume of water added. It is an indication that wheat–maize composite dough volume did not increase proportionally with added water. Maize flour has lower swelling power, as reflected in their pasting viscosities (Oladunmoye *et al.*, 2004b). This behaviour also suggested decrease in weight of wheat- maize composite dough with increase in level of substitution.

Thermal properties

The specific heat capacity of whole-wheat bread-dough at 38 °C with a moisture level of 43.14% was 2.72 ± 0.53 kJ kg^{-1}K. Other researchers as reviewed by Johnsson & Skjoldebrand (1987) on wheat dough have reported similar results. Wheat–cassava composite bread dough specific heat capacity increase with increased in level of substitution (Fig. 4). There was 7.9% decrease in specific heat value with 40% wheat substitution with cassava flour. Contrarily to the above trend, as wheat substitution with cassava increased to 50%, 60% and 100%, a further increase by 9.3%, 3.1% and 4.9% in specific heat was respectively observed. This could be due to the low damaged starch content of cassava flour, which allows strong bonds to be formed between starch granules and water molecules (Satin, 1988). The method of dough preparation possibly accounts for this, the bonds within the starch granules having been denatured to a reasonable extent (Chilton & Collison, 1974). Comparatively, the specific heat values obtained for wheat–maize composite bread dough were lower than that for 100% wheat bread dough. The reduction levels reduce (35%, 32% and 4%) as the substitution increases (40%, 50% and 60%) with maize

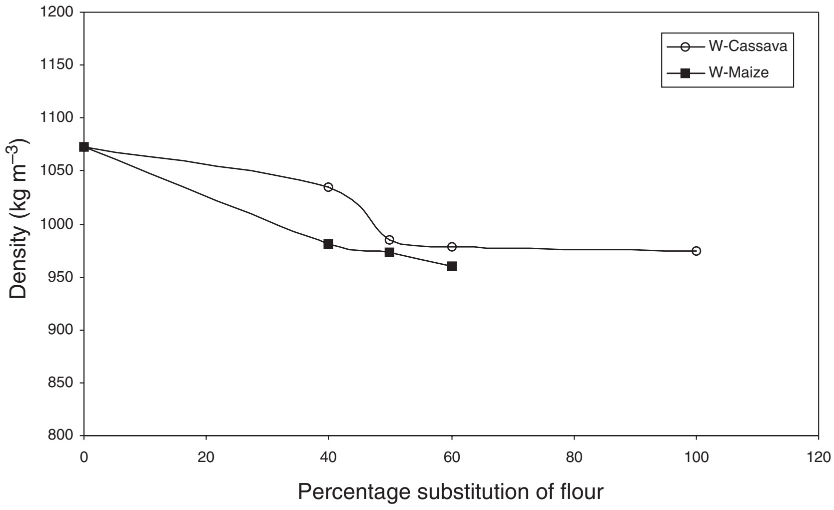

Figure 3 Density of composite bread dough as influenced by proportional composition.

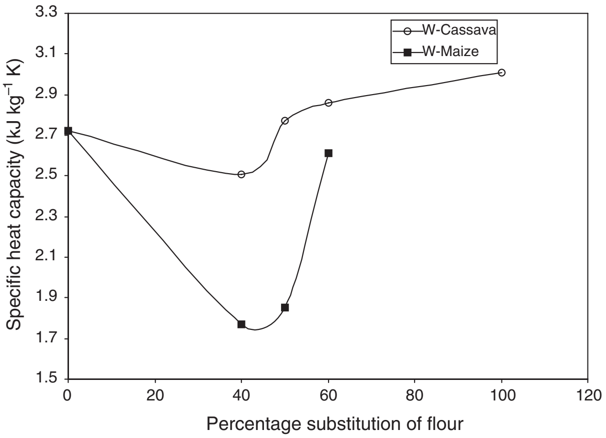

Figure 4 Specific heat capacity of composite bread dough as influenced by proportional composition.

flour. This could be attributed to the high level of damaged starch in maize flour (Gevaudan *et al.*, 1989). Change in binding energy between starch and water molecules have been shown to contribute to the specific heat of a material (Pfalzner, 1951). The coefficients of determination R^2 for wheat–cassava and wheat–maize bread dough regression model were 0.657 and 0.779 respectively (Tables 2 and 3). Influence of the ratio of flours were not significant on specific heat capacity of dough at $P < 0.05$.

As shown in Fig. 5, thermal conductivity of composite bread dough rises with increase in levels of substitution for the two composite flours. Variations of the thermal conductivity of both wheat–cassava and wheat–maize composite bread dough ranged from 0.362 ± 0.13 to 0.473 ± 0.12 W mK^{-1} and 0.36 ± 0.07 to 0.39 ± 0.02 W mK^{-1} for wheat–cassava and wheat–maize respectively. This behaviour may be traced to differences in the moisture content earlier mentioned. One per cent moisture content dry basis change would affect the value of thermal conductivity of palm kernel by 0.064 W m^{-1} °C^{-1} (Obetta, 2000). Similarly, Mukherjee & Chattopadhyay (2002) reported increase in thermal conductivity of potato from 0.0889 to 0.6395 W m °C^{-1} as the moisture content and temperature were simultaneously increased from 0.33 to 4.88 kg kg^{-1} (db) and 20 to 90 °C, respectively. Using linear regression model to analyse the relationship gave high coefficient of determination of R^2 (0.879) and (0.962) for wheat–cassava and wheat–maize, respectively. Also, effects of substitution significantly affect the thermal conductivity of both composite dough at $P < 0.05$ (Tables 2 and 3).

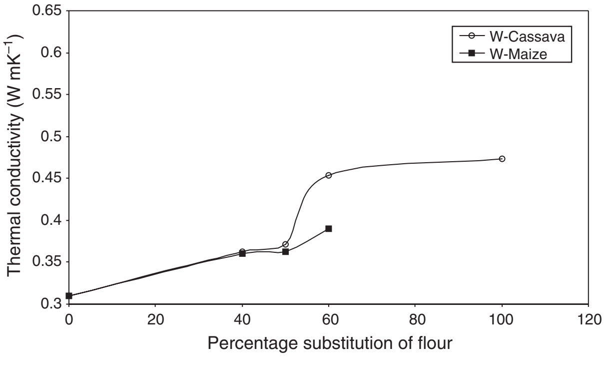

Figure 5 Thermal conductivity of composite bread dough as influenced by proportional composition.

At the early stages of baking operation, wheat, cassava and maize breads went through a lag phase for about 8–10 min. During this period, the dimensionless residual temperature varied only slightly from 1.0. However, as baking progressed, the variation between their dimensionless residual temperatures became wider, that of maize being highest followed by cassava composite bread. These show that heat penetration into maize and cassava bread dough occurred at a lower rate compared to wheat. Hence, it would take a longer time to bake maize and cassava bread in comparison to wheat bread. According to Brown (2002), the work input during mixing results in change in internal energy of the dough and this is associated with thermal properties. Rate of heat transfer in unsteady state is known to be directly proportional to the thermal conductivity and inversely proportional to density and specific heat capacity of the material (McCabe *et al.*, 2005). Thus the observed variation may be associated to these thermo-physical properties.

Conclusion

This work has shown that moisture content, density, specific heat capacity and thermal conductivity of wheat–cassava and wheat–maize composite bread dough varied with levels of substitution and composites. Moisture content and thermal conductivity of the dough were significantly influenced at $P < 0.05$ while effects were non significant on density and specific heat capacity at same levels of prediction. Specific heat capacity of wheat–cassava dough was higher than that wheat–maize dough, indicating that more energy would be required in baking wheat–maize bread. Similarly, it would take a longer time to bake wheat–maize bread than wheat–cassava bread. Moisture content and thermal conductivity of 100% wheat flour were lower than those of composite flours while densities of the flours showed reversal. Specific heat capacities fluctuate. Data provided on thermo-physical properties of composite bread dough will be useful in simulating baking process. Also the information will be relevant in designing new ovens or modifying the efficiency of the existing ones for baking of wheat-less bread.

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