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Effect of blend levels on composite wheat doughs performance made from yam and cassava native starches and bread quality

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ABSTRACT

The effects of refined wheat flour substitution with two native starches from yam tuber and cassava root, and two commercial products, a specialty starch, C*Actistar and a wheat bran flour, at 10%, 20%, 30%, 40% and 60% dry basis, on the rheological properties of dough and bread characteristics, have been examined. In general, during the mixing phase, the substitution of white wheat flour for starch or wheat bran flour had a tendency to modify the flour strength from strong to weak, depending on the nature of the added fraction and the level of substitution. Yam starch and wheat bran flour weakened dough strength to a lesser extent in comparison with cassava starch, and by far, the resistant starch, C*Actistar. In addition, differences in dough expansion appeared among the botanical origins of composite dough and the blend proportions, during the fermentation phase. White wheat flour substitution for yam starch up to 30% or cassava starch up to 20% led to kinetics expansions of resulted doughs close to that of the control, while those of doughs containing C*Actistar starch or wheat bran flour were significantly slower than that of the control, whatever the level of substitution. The baking phase showed that yam starch enriched breads from 10% to 40% of substitution and cassava starch enriched breads from 10% to 30% of substitution gave as bulky loaves as the refined wheat bread. Beyond these concentrations, the resulting breads were less voluminous. Hedonic tests revealed that, 30% yam starch substitution and 20% added cassava starch led to composite breads which met consumer satisfaction on all attributes, as the control.

1. Introduction

Due to the high cost, geographical scarcity and high demand of wheat flour, efforts are been directed toward the provision of alternative sources of flours, notably in tropical areas. In Africa, flours from cereal plants such as sorghum (Anonymous, 1982; Balla, Blecker, Oumarou, Paquot, & Deroanne, 1999), millet (Anonymous, 1982), and maize (Anonymous, 1982), and from cassava roots (Eddy, Udofia, & Eyo, 2007; Shittu, Raji, & Sanni, 2007) have been generally studied for the substitution of wheat flour in bread-making. The substitutions of wheat flour by these starchy staples led to more or less satisfying bread products. However, composite wheat breads generally displayed reduction in loaf volume and impairment of sensory qualities (e.g. appearance, texture, and flavor), as the level of substitution of wheat with non wheat flour increased (Olaoye, Onilude, & Idowu, 2006; Peressini & Sensidoni, 2009; Sudha, Vetrimani, & Leelavathi, 2007). Due to the fact that the main selection criteria of wheat are based on their ability to give bulky white breads, it appeared useful to seek products of substitution which had less negative impacts on the volume of the bread. For this purpose, some authors suggest that it is necessary to have a low content of ashes in the composite flours of cereals or roots used in bread-making process to obtain bread with a pleasant crumb colour and taste (Özboy & Köksel, 1997; Zhang & Moore, 1997). Ciacco and D'Appolonia (1978a) showed that, the cassava starch was more appropriate than the cassava flour in bakery, due to its absence of fibre. Earlier studies also revealed that the addition of fibre reduced crumb hardness after storage (Korus & Achremowicz, 2004; Korus, Grzelak, Achremowicz, & Sabat, 2006). Rheological properties of dough are also important for both product quality and process efficiency. Evidently, the expansion capacity is determined by the gas cell structure and the rheological properties of the dough, at the end of mixing. Greater elongation of dough is associated with greater tolerance to distortion, before rupture. Yam starches, which are highly stable to thermal treatment and resistant to shearing (Amani, Kamenan, Rolland-Sabaté, & Colonna, 2005), could show relevant properties in dough expansion. For this purpose, Ciacco and

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D'Appolonia (1978b) showed that flour samples from some water yam genotypes were not inferior to cassava flour in bread making.

Consequently, the present work aimed to determine the blend proportions of composite soft wheat flours made from starches of native cassava and yam clones, giving rheological dough properties close to those of soft wheat dough. The target is to get the optimum composite formulation, leading to the maximum bread volume for the maximum level of white wheat flour substitution. Such study enters in the frame of local food crops promotion and the reduction of negative balance of trade in developing countries.

2. Materials and methods

2.1. Materials

Previous study showed that a native starch belonging to *Dioscorea cayenensis-rotundata* var. Kangba, was highly thermostable and resistant to shearing (Amani, Buleon, Kamenan, & Colonna, 2004). Thus, this yam variety was used in this present study. A hybrid cassava clone, 98/0325, from the genotype collection of the International Institute of Tropical Agriculture (IITA), was also used, due to a relatively high peak viscosity of its starch paste, as a cassava clone (personal communication). The yam and cassava clones were grown at the experimental farm of the University of Abobo-Adjamé, in Côte d'Ivoire. The plants were harvested, at maturity, after 8 months of plantation for yam clone, and after 12 months for cassava clone. The starches of these roots and tubers were extracted. A specialty starch, C*Actistar 11700 was offered by Cerestar-Cargill (Vilvoorde, Belgium). C*Actistar 11700 contains 58% of resistant starches, made by crystallizing hydrolyzed tapioca starch (maltodextrins). A white wheat flour (Flour G) and a wheat bran (Flour G) were obtained from the manufacturer Mill of Statte, in Huy (Belgium). Flour blends were made with the raw materials used. White wheat flour, used as control (100% white wheat flour) was progressively substituted with other powders. Thus, yam starch/wheat flour blends, cassava starch/wheat flour blends, C*Actistar starch/wheat flour blends, and wheat bran flour/wheat flour blends were prepared with, respectively, 10%, 20%, 30%, 40% and 60% of white wheat flour substitutions.

2.2. Starch isolation

Yam tubers or cassava roots were peeled and immediately cut into small pieces (Amani et al., 2004). The freshly cut pieces were suspended in distilled water containing 0.1% (w/v) sodium metabisulphite. The material was crushed in a Warring blender (Moulinex, Lyon, France) and suspended in a large excess of distilled water containing 4% NaCl. The slurry was filtered through a 100 μm sieve. The starch granules were centrifuged at $2660 \times g$ for 15 min. This process was repeated four times and the recovered white prime starch was then oven-dried at 45 °C during 48 h. The dry product was crushed and canned.

2.3. Chemical analyses

2.3.1. Moisture

Moisture content was determined by heating sample (2–3 g) at 130 °C, in an air oven for 1 h (American Association of Cereal Chemists, 2000).

2.3.2. Starch damage

Starch damage was determined according to Chopin SD4 method (Rogers, Gelroth, Langemeier, & Ranhotra, 1994). The measurement of the starch damage was based on the ability of the starch to fix iodine – the more so when the starch is damaged. 1 g on dry basis of sample was weighted and mixed in 3 mL of ethanol. 100 mL of decarbonated water, 20 mL hydrogen chloride and 10 mL potassium iodide were added. The mixture was analyzed by an SD4 machine and the starch damage was determined in UCD units by adding KIO_3 solution. This investigation was conducted on the raw materials. All analyses were performed in duplicate and mean values were calculated.

2.3.3. Starch and amylose contents

The starch content was determined according to the polarimetric method of Ewers (ISO, 1997a). This method consisted of two determinations. In the first step, the sample was digested in a hot chloride acid solution. After digestion (precipitation of nitrogen compounds with acetate ferric) and filtration, optical activity of the solution was measured by polarimetric method. In the second phase, dissolved components of the sample were discarded after dissolution in ethanol 40%. After acidification of the precipitate by hydrogen chloride, digestion and filtration, the optical activity was measured in the same condition as the former determination. The starch content is the difference between both determinations, multiplied by a specific factor. The apparent amylose was measured by colorimetric determination according to the Morrison and Laignelet method (Morrison & Laignelet, 1983). The absorbance of the blue amylose–polyiodide complex produced was determined, and amylose content was calculated from a standard curve using mixtures of pure potato amylose and amylopectin (over the range 0–30% amylose).

These investigations were conducted on raw materials. All analyses were performed in triplicate and mean values were calculated.

2.4. Thermal properties (Kim, Wiesenborn, & Grant, 1997)

DSC was performed on a TA Instruments 2920 device (New Castle, DE) using hermetic aluminum pans. The sample pan (3 mg of starch on dry basis dissolved in 12 μL of ultrapure water) and the reference pan (12 μL of ultrapure water) were heated from 25 °C to 180 °C at a scanning rate of 10 °C/min, held for 2 min at 180 °C, and cooled to 25 °C at 10 °C/min. The enthalpy of gelatinization, the onset temperature, and the peak temperature of each sample were then determined on the thermograms. This analysis was conducted on raw materials. Three replicates of each sample were carried out.

2.5. Farinograph properties

The farinograph test measures and records the resistance of dough to mixing with paddles. A 300 g flour sample on a 14% moisture basis was weighed and placed into the corresponding farinograph mixing bowl (model Farinograph-Resistograph®, No. 187517 Type 827503, Brabender® OHG, Disburg, Western Germany). Water from a burette was added to the flour and mixed to form a dough. As the dough was mixed, the farinograph recorded a curve on graph paper. The amount of water added (absorption) affected the position of the curve on the graph paper. Less water increased dough consistency and moved the curve upward. The curve was centered on the 500-Brabender unit (BU) line ± 20 BU by adding the appropriate amount of water and was run until the curve left the 500-BU line. According to the method ISO 5530-1:1997 (ISO, 1997b), the properties of water absorption, the time of dough development and the stability of the paste were determined. The water absorption of the flours corresponded to the quantity of water to obtain 500 BU (an arbitrary consistency). The time of dough development corresponded to the time needed for the paste to reach its maximum consistency, before gluten strands begin to break down. The stability corresponded to the time (min) during which the paste remained unchanged, without a fall in viscosity, and this parameter is a good indication of dough strength. The softening or fall of viscosity was determined at the end of mixing time. This parameter is generally considered the point at which gluten is breaking down and dough has become over mixed. This investigation was conducted on flour blends. All analyses were performed in triplicate and mean values were calculated.

2.6. Baking procedure

According to AACC 10-10B method (American Association of Cereal Chemists, 2000), the pan bread formula contained: flour (300 g), sucrose (18 g), salt (4.5 g), fat (3 g), yeast (15.9 g) and variable water on the basis of farinograph water absorption. After kneading, the paste was rounded and left to rise at room temperature during 20 min. Then, the loaves were moulded before being placed, during 60 min, in a fermentation chamber (Iverpan, Salva, France), whose moisture and temperature were regulated, respectively, at 85% and 30 °C. Cooking was performed at 220 °C, during 20 min, in an oven (Nidur, Salva, Belgium) equipped with a system of water vapor injection. After baking, the loaves were removed from the pan, and cooled during 2 h, at room temperature, before weighing. The determination of volume was carried out using a volumeter (Puratos, Belgium). The density or the specific loaf weight of the breads was given by the ratio between the weight of the bread after cooling and its volume. The properties of gas retention during fermentation were evaluated using an indicator of dough development containing 25 g of paste subjected to fermentation, under the same conditions as the loaves, i.e. 85% RH and 30 °C. This volumeter is graduated with 30 graduations separated by 2 mm from level 1 to level 7 (60 mm high), level 1 correspondent to a volume of 20 cm^3. These analyses were conducted on flour blends. Three replicates of each sample were carried out.

2.7. Sensory evaluation

A nine point hedonic rating scale (Lawless & Heymann, 1999) was used to determine the acceptability of composite wheat breads. The panel consisted of forty untrained assessors, who evaluated bread overall acceptability, crumb colour, crumb appearance, and overall texture and taste. A score of 1 represented “dislike extremely” and a score of 9 represented “like extremely”. Samples were randomly coded and served individually.

2.8. Statistical analyses

All experiments were performed in a completely randomized design. Statistical differences in dough and bread properties were determined by one-way analysis of variance (ANOVA) and Duncan's multiple range test ($p < 0.05$) (SAS software version 8.2).

3. Results and discussion

3.1. Proximate composition of raw materials

Table 1 shows that the yam starch sample was moister than the white wheat flour, while the other samples were less moist than the control. All starches studied were less or equally damaged than those of the control, i.e. commercial white wheat flour. Chemical properties showed that starch contents from the yam (78.9 g/100 g) and the cassava clones (80.7 g/100 g) were higher ($p < 0.05$) than those from white wheat flour (69.7 g/100 g) and wheat bran flour (28 g/100 g), but lower ($p < 0.05$) than C*Actistar starch content (94.3 g/100 g). The amylose content from the yam clone (43.4%) was also higher ($p < 0.05$) than those from white wheat flour (25.9%) and wheat bran flour (27.6%), but close to C*Actistar amylose content, for which the value was the greatest (50%). In a previous study, the maximum amylose content among

Table 1
Proximate composition of raw materials.

Product	Botanical source	Chemical properties						Thermal properties		
		Moisture (% fresh matter)	Damaged Starch (UCD[a])	Starch (g/100 g db)	Apparent amylose (%)	Protein (g/100 g db)	Ash (g/100 g db)	Tg_Onset[b] (°C)	Tg_Maxi[c] (°C)	ΔH[d] (J/g)
Kangba starch	*Dioscorea cayenensis-rotundata*	14.45a	11.70b	78.94b	43.45b	0.25d	0.14c	74.43b	78.73b	13.58b
98.0325 starch	*Manihot esculenta*	10.49c	11.6b	80.71b	29.10c	0.12d	0.18c	66.64c	71.56b	13.86b
C*Actistar starch	*Manihot esculenta*	8.00d	1.50c	94.30a	50.00a	1.50c	0.10c	110.23a	115.97a	107.70a
Wheat bran flour	*Triticum aestivum*	12.00b	1.30c	28.00d	27.60c	15.55a	4.00a	57.70d	63.65c	11.80bc
White wheat flour	*Triticum aestivum*	13.05b	21.00a	69.68c	25.90c	12.00b	0.60b	59.90d	65.03c	9.79c

Values with similar letters did not differ significantly (Duncan's multiple range test, $p < 0.05$).
[a] Unité Chopin Dubois.
[b] Onset temperatures (°C).
[c] Peak temperatures (°C).
[d] ΔH: transition enthalpy (J/g).

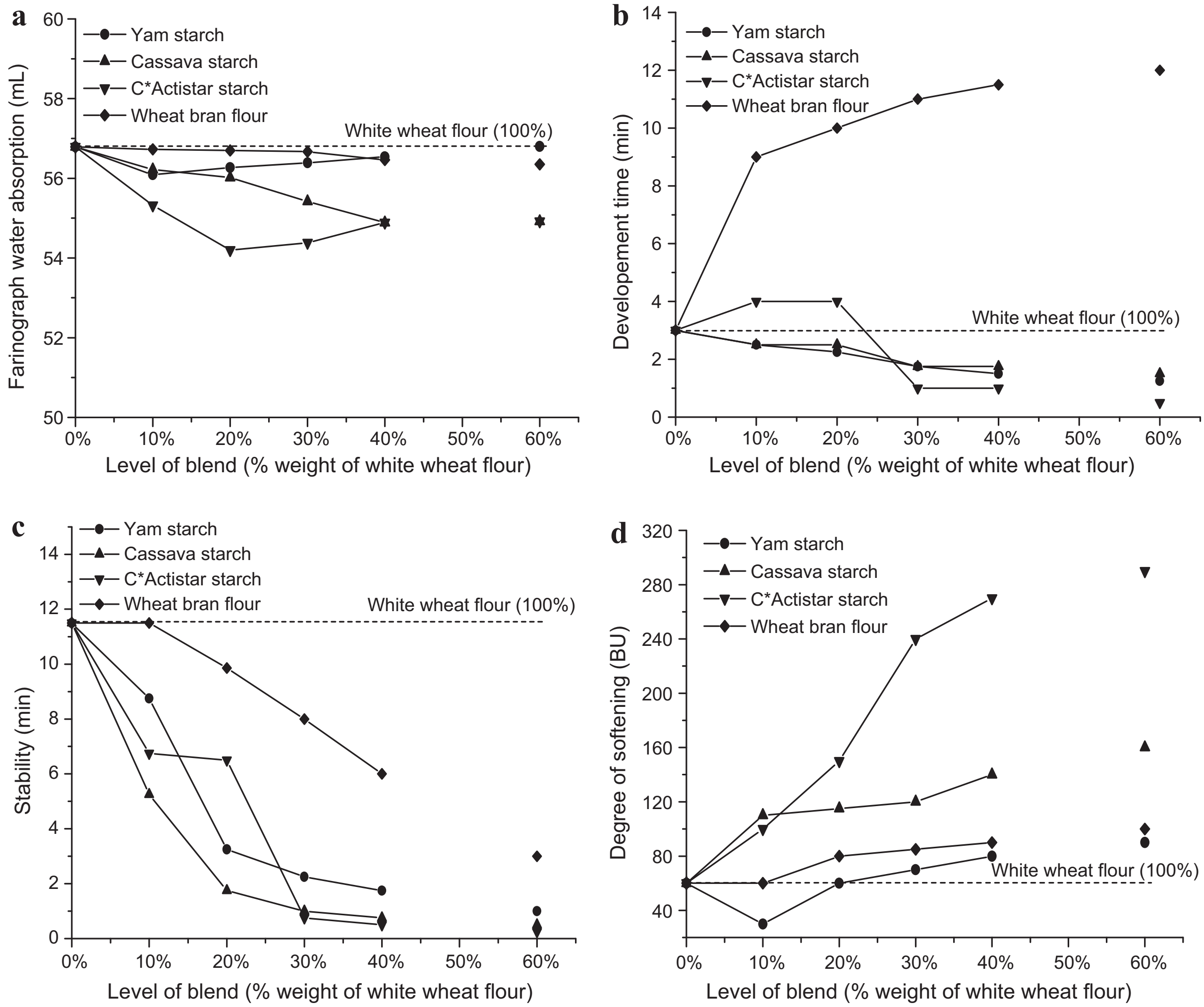

Fig. 1. Rates of farinograph properties of composite wheat flours: (a) farinograph water absorption, (b) development time, (c) stability, and (d) dough softening.

the root and tuber starches studied was observed in yam starch at 30.36% for total amylose (Huang, 2009). A relatively high amylose content from the cassava clone (29.10%) in the present study was not significantly different ($p > 0.05$) from wheat flour values. The protein and ash contents from yam and cassava starches and from C*Actistar starch were by far lower ($p < 0.05$) than those of wheat flour samples (Table 1). The low content in protein from starch samples predicted their weak predisposition to develop the gluten network in breadmaking. However, their low content in ash would be a favourable contribution to obtain bread with a pleasant crumb colour and taste, as previously suggested by other authors (Özboy & Köksel, 1997; Zhang & Moore, 1997). The thermal properties showed that the resistant starch C*Actistar had the highest enthalpy of gelatinization (107.7 J/g), followed by far by those of yam (13.58 J/g) and cassava (13.86 J/g) starches, and the lowest values were found for white wheat flour (9.79 J/g) and wheat bran flour (11.8 J/g). The same pattern was observed with the onset and peak temperatures. This suggests stronger bonds in molecular structures of pure starches from C*Actistar, yam and cassava than in those from wheat flours.

3.2. Farinograph properties of doughs

Fig. 1a shows that the farinograph water absorption of yam starch-white wheat flour blend and wheat bran flour-white wheat flour blend remained, in general, close to that of 100% white wheat flour, whatever the levels of substitution. The same trend occurred for cassava starch-enriched white wheat flour at levels of substitution up to 20%, but above this level, the farinograph water absorption decreased. Moreover, the farinograph water absorption of composite flours containing C*Actistar starch notably decreased with the substitution of white wheat flour. The water absorption of the flour depends on the swelling substances in the wheat (proteins and pentosans), and the mechanically damaged starch granules (Guttieri, Bowen, Gannon, O'Brien, & Souza, 2001). A greater level of water absorption of composite flours involving yam or cassava starch, in comparison with that of C*Actistar-enriched flour, was observed, and that could be due to a higher content of damaged starch in yam starch (11.7 UCD) and cassava starch (11.60 UCD) than in C*Actistar starch (1.50 UCD) (Table 1). It is well known that the starches from C*Actistar are damaged, but its low content of damaged starch is attributable to the retrograded state of the starch, leading to a dense structure at which the fixation of iodine occurs with difficulty. According to Tipples (1969), damaged starch causes a linear increase in the water absorption capacity of flour. Although the damaged starch content of wheat bran flour was low (1.30 UCD), the composite flours containing this fibre showed levels of water absorption relatively high and close to that of the control. Thus, this result in the present study showed that the water uptake remained almost unvaried, whatever the level of wheat bran flour addition. On the contrary, other results reported that the addition of bran samples from different sources mainly increased the water absorption (Mariotti, Lucisano, & Pagani, 2006; Sudha et al., 2007). In any case, the fact that the amount of water absorption of the flour containing wheat bran did not decrease, whatever the level of substitution, could be due to a high water-binding capacity of fibres. Similar findings on moisture affinity related to bran were reported by Wang, Rosell, and Benedito de Barbera (2002), suggesting that the highest water absorption in fibre-enriched wheat dough was found with the addition of pea fibre, followed by carob fibre. Other authors (Pomeranz, Shogren, Finney, & Bechtel, 1977; Sanz Penella, Collar, & Haros, 2008) observed similar effects on water absorption, when adding wheat bran. This is likely caused by the great number of hydroxyl groups existing in the fibre structure, which allow more water interactions through hydrogen bonding, as was previously found by Rosell, Rojas, and Benedito de Barber (2001), working with different hydrocolloids. In Fig. 1b, we observed that the development times of composite doughs containing C*Actistar, yam or cassava starches were close to that of the control, when the levels of white wheat flour substitution did not exceed 20%, but above this amount, their development times notably felt. On the contrary, the development times of composite dough made from wheat bran flour sharply rose with wheat flour substitution. When wheat flour is mixed with water, a complex protein called gluten is formed. This component is, in reality, the skeleton of wheat flour dough, and plays an important role in gas retention, which makes the light, leavened products. The gluten development is what gives wheat dough an elastic structure that allows it to be worked in a variety of ways (Aboaba & Obakpolor, 2010). Therefore, the substitution of a part of wheat flour for flours containing no-gluten-forming proteins decreases the total weight of wheat protein, resulting in a skeleton weaker than that of 100% white wheat flour dough. The dough development time was shortened, and that might be due to a decrease of cohesivity and swelling capacity of the dough, as the white wheat flour substitution for different sources of starch was over 20% (Fig. 1b). An opposite effect occurred with doughs containing wheat bran, and that might be due to a higher water uptake of bran. This competition for water between dietary fibres and protein, delayed the development of gluten network, as previously reported by Rosell, Santos, and Collar (2006), and therefore, lasted the dough development time. Similar results on bran samples have been found by Sudha et al. (2007) suggesting that the extent of increase in dough development time was high in the case of wheat and rice bran blends. According to Sanz Penella et al. (2008), bran concentration had a positive significant linear effect in the time to reach maximum consistency. Dough stability, which indicates how much additional mixing can be imparted to a dough before it begins to break down, was measured (Fig. 1c). For all blends, stability drastically decreased with increased substitution of white wheat flour, but to a lesser extent for wheat bran enriched dough. The drop in stability indicated an overall weakening of the composite doughs, as white wheat flour substitution increased. The weak development of gluten network caused by addition of starch or wheat bran, led to a decrease of dough elasticity, an essential quality for dough to become malleable and resistant to mixing before breaking down. This loss of gluten elasticity is pointed out by the decrease in the width of the farinograph curve (Mariotti et al., 2006), i.e. the dough stability. Similar results on the weakening of the dough were reported by Laurikainen, Härkönen, Autio, and Poutanen (1998), and Sudha et al. (2007), when bran samples from different sources were added, in disagreement with other findings (Sanz Penella et al., 2008; Wang et al., 2002). In Fig. 1d, the degree of softening for all types of composite doughs increased with the amount of white wheat flour substitution, but to a lesser or greater extent, depending on the nature of added fraction. Yam starch-enriched dough and dough containing wheat bran showed the lowest degrees of softening, following by the cassava starch-enriched dough. C*Actistar-enriched dough had the highest degrees of softening. The low amount of protein in cassava starch and C*Actistar led to a weak development of gluten network, and consequently to a weak dough cohesivity and elasticity. The mechanical stress of the farinograph mixer imparted to the dough met a weak kneading resistance, that resulted in a quickly breakdown of gluten network, especially for C*Actistar, over the mixing time. Nevertheless the same pattern occurred as the former starches, yam starch led to a relatively low decline in viscosity by over-mixing. That could be due to the resistant property of yam starch to shearing (Amani et al., 2005), which contributed to break the fall of viscosity, to a certain extent, through the interaction with gluten. Concerning the wheat bran, that might be the tangling up of fibres into viscous mass of the dough which lessened the viscosity breakdown at over-mixing time. Similar effects on degree of softening were reported by Sudha et al. (2007), who suggested that greater positive effects were observed on the mixing tolerance index values, when bran samples from different sources were added.

Dough development time and stability value are indicators of the flour strength, with higher values suggesting stronger doughs (Wang et al., 2002). Wheat flours described by bakers as “weak” reach the 500 BU mark quickly and show no stability before undergoing a considerable decline in viscosity (American Association of Cereal Chemists, 2000). The “strong” flours take longer to develop, before reaching the 500 BU mark, where they remain for some time, at a good stability and then, show a minor decline in viscosity. Thus, the composite doughs made from yam starch, cassava starch or the resistant starch, C*Actistar had a short dough development time and were less stable during mixing, as increased white wheat flour substitution. Unlike cassava starch, and particularly the resistant starch, C*Actistar, yam starch induced a greater tolerance to overmixing, close to that of the refined wheat dough. On the contrary, the doughs containing wheat bran flour took longer to develop, but were also less stable, as increased bran addition. Furthermore, wheat bran induced a greater tolerance to overmixing, as yam starch. In any case, the different sources of pure starch and the wheat bran induced less stable dough during mixing, unlike control dough. Therefore, the substitution of white wheat flour for starch or wheat bran led to a weakening of the gluten strength of composite doughs, as previously found by other authors (Ammar, Hegazy, & Bedeir, 2009; Mariotti et al., 2006; Sudha et al., 2007).

3.3. Composite wheat dough expansion during fermentation phase

In general, all of composite doughs and control showed an expansion, varying from 0.25 to 2 times their initial heights, during paste fermentation (Fig. 2). In addition, differences appeared among the botanical origins of the added fraction and into the blend proportions.

Concerning botanical origins, Fig. 2a and b shows that the final steps of swelling (after 60 min) varied from level 3.2 to level 5, for the wheat bran-enriched doughs and the doughs containing C*Actistar, while the composite doughs from yam starch (Fig. 2c) and cassava starch (Fig. 2d) grew more, reaching maximum levels from 5 to 7, like the control. During fermentation, the dough undergoes a process of inflation in which the carbon dioxide enlarges the pores and gives the dough greater volume (American Association of Cereal Chemists, 2000). In the present study, yam starch, cassava starch and white wheat flour, were more sensitive to carbohydrate degradation to produce carbon dioxide than wheat bran and C*Actistar starch. This sensitivity is explained by a higher composition of yam starch, cassava starch, and white wheat flour, in damaged starches (Table 1), which were more easily degraded by chemical or enzymatic hydrolysis. Indeed, the poor dough develop-

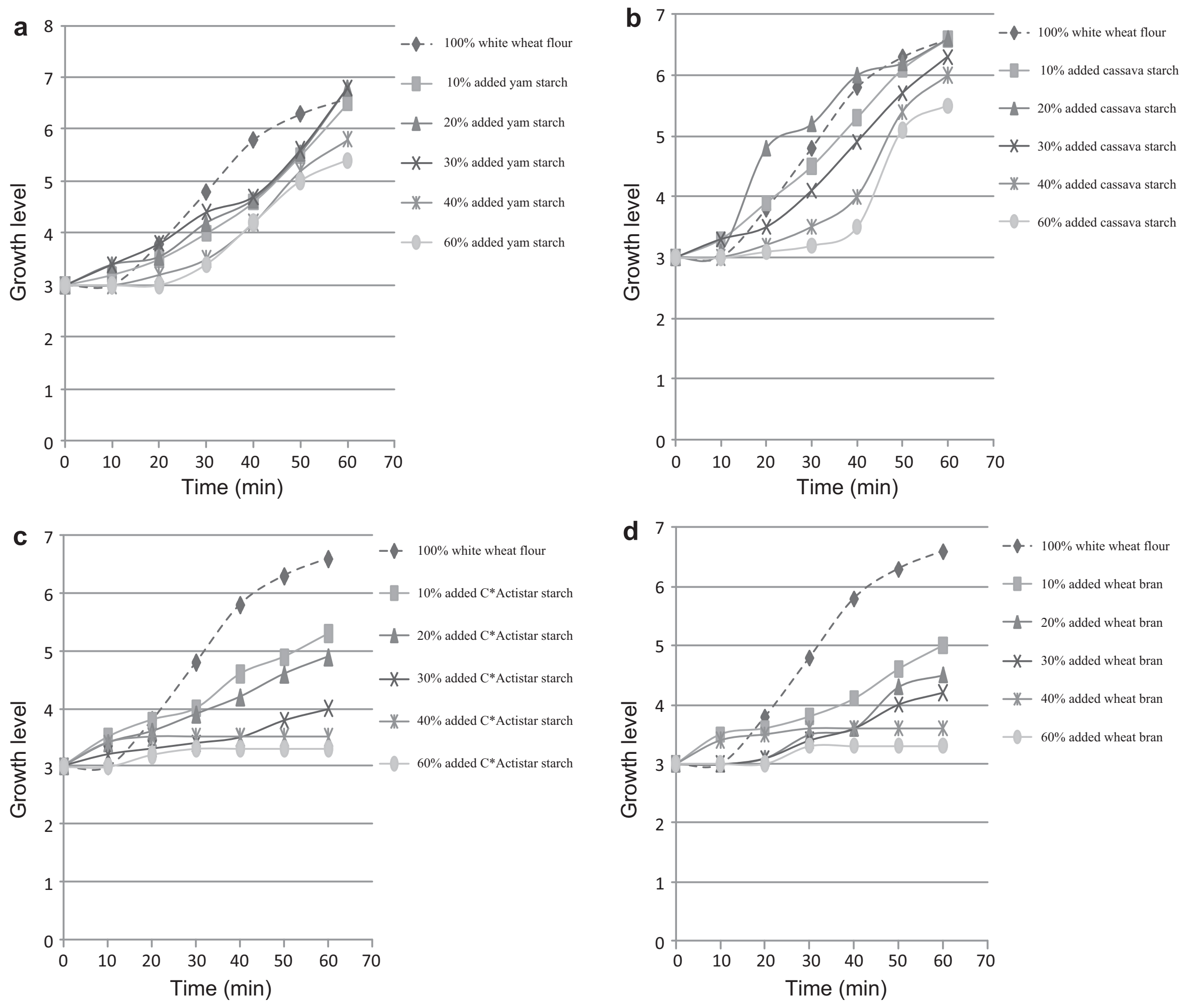

Fig. 2. Composite wheat dough growth during fermentation: (a) yam starch, (b) cassava starch, (c) C*Actistar starch, and (d) wheat bran flour.

ment of composite doughs made from wheat bran and C*Actistar starch was the result of low gassing power during fermentation (Sanz Penella et al., 2008). Protein quality and quantity play important roles in the dough for efficient gas retention, during fermentation and early stages of baking (Hayta & Cakmakli, 2001). Wheat bran prevents the hydration of the proteins, so the ability of gluten proteins to form a viscoelastic network was reduced, affecting gas retention capacity, and leading to a low volume yield. Indeed, the low gassing power induced by wheat bran could be explained by its low content in starch (Table 1), source of fermentable substrates. C*Actistar starch, which is a resistant starch, was not easily degraded into fermentable substrates, resulting in a poor gas production and a low volume yield. For this purpose, Haralampu (2000) noticed that resistant starch (RS) encompasses forms of starch, which are not accessible to digestive enzymes. By far, retrograded starch, and particularly retrograded amylose, is the most thermally stable forms.

As for blend proportions, Fig. 2 shows that the profile of 100% white wheat dough presented a sigmoid appearance. This dough did not rise during the first 10 min of fermentation, then it sharply rose during the following 30 min, and after that, the growth slowed down. After substitution of a part of white wheat flour, the growth of all resulting composite doughs increased slowly during the first 10 or 20 min. Then, a more or less long plateau phase occurred and remained constant, as observed when refined wheat flour was highly substituted (40% and 60%) for C*Actistar starch (Fig. 2c) or wheat bran flour (Fig. 2d). When the levels of substitution by C*Actistar starch or wheat bran flour were lower (10% and 20%), the inflation phase of the resulted composite doughs was slightly more visible. On the contrary, the slopes of the inflation phase were higher, when yam starch (Fig. 2a) and cassava starch (Fig. 2b) were used as added fractions. In general, dough expansions gradually decreased with increasing levels of added starch or flour. The formulations from 10 to 30% of substitution for yam or cassava-enriched dough, led to a dough development close to that of the control. Beyond 30% of substitution, dough expansions were significantly slowed. As for C*Actistar or wheat bran enriched dough, no formulation led to a dough expansion close to that of 100% white wheat dough. Gas retention directly depends on the consistency of the dough. Firm doughs with a high gas retention combined with good gas production result in a high volume yield (American Association of Cereal Chemists, 2000). Yam or cassava-enriched wheat flour induced greater gas production than composite flour containing C*Actistar or wheat bran, due to their higher composition in damaged starch. However, the increase of levels of yam starch or cassava starch into the composite doughs did not induce a rise of pastes. In fact, the gas production ought to increase with the substitution by yam starch or cassava starch, but it did not occur like that, due to a weakening of the viscoelastic network, induced by a decrease of the gluten quantity. Thus, the gas retention capacity decreased, and the resulted doughs slightly grew. This situation of a low volume yield occurred to a greater extent, when the fraction of C*Actistar or wheat bran flour increased into the composite doughs, due to the combined effects of poor gas production and low

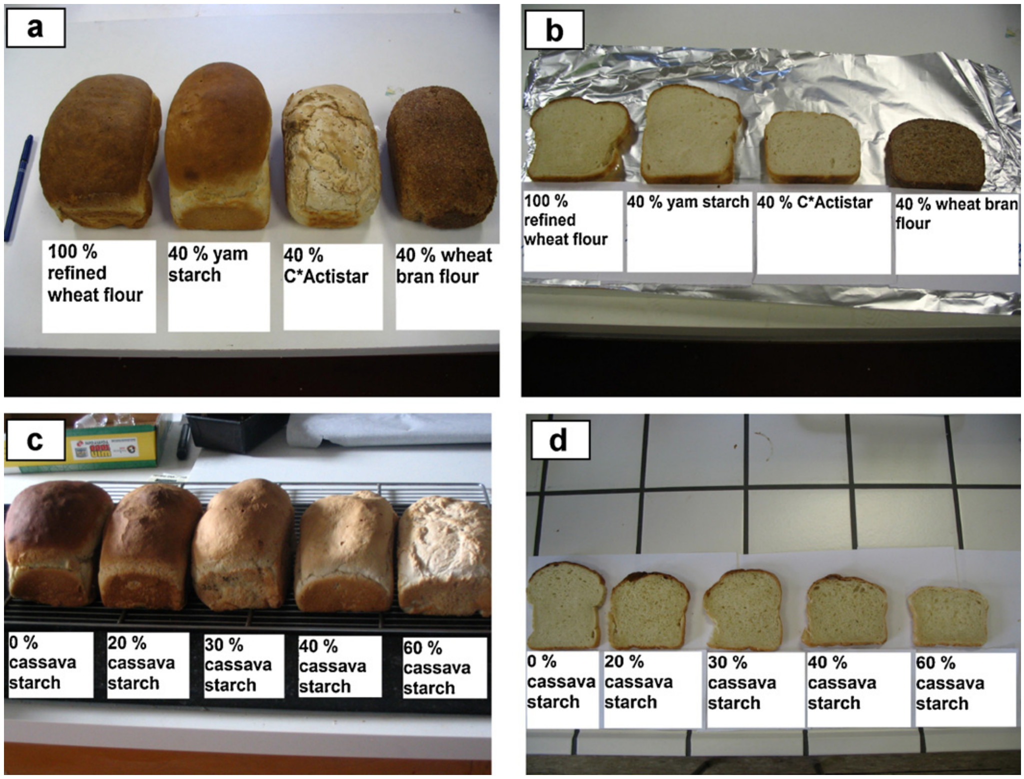

Fig. 3. Sizes of the composite breads, depending on quality of added fraction ((a) loaf or (b) slice forms) or the quantity of cassava starch incorporated ((c) loaf or (d) slice forms). An added fraction of 40% has been used as example, to test the effect of the quality. The quantity of cassava starch incorporated, ranging from 20% to 60%, was done as percentage of substituted white wheat flour.

gas retention capacity generated. Similar results have been found by Aboaba and Obakpolor (2010), when they suggested that the inclusion of cassava flour significantly reduced the leavening profile of the dough especially as the quantity increased beyond 20% at room temperature. Mariotti et al. (2006), also reported that dough height was negatively affected by oat flour, with a 40% decrease at the higher supplementation level.

3.4. Final baked volume of composite wheat breads

Fig. 3a and b shows that substitution of refined wheat flour for C* Actistar or wheat bran flour visibly reduced the volume of resulted breads, while this effect occurred to a lesser extent, when native yam starch or cassava starch were used. In addition, the more refined wheat flour fraction was substituted for all types of starch

Table 2
Loaf specific weight[a] of breads made from composite wheat flours.

Product	Blend (% white wheat flour)	Loaf volume (mL)	Loaf weight (g)	Loaf specific weight[b] (g/mL)
White wheat flour	100	1600	416.41	0.26a
Yam starch	10	1600	418.00	0.26a
	20	1625	425.00	0.26a
	30	1625	425.11	0.26a
	40	1525	413.54	0.27a
	60	1150	390.92	0.34c
Cassava starch	10	1700	431.81	0.25a
	20	1550	424.31	0.27a
	30	1650	429.35	0.26a
	40	1500	429.00	0.29b
	60	1100	390.92	0.36c
C*Actistar	10	1500	440.00	0.29b
	10	1200	450.00	0.38d
	30	1000	460.50	0.46e
	40	800	469.74	0.59f
	60	600	470.70	0.78h
Wheat bran flour	10	1400	430.00	0.31b
	20	1300	440.00	0.34c
	30	1000	451.24	0.45e
	40	700	463.96	0.66g
	60	500	464.00	0.93i

[a] Loaf mass/volume.
[b] Means with the same letter within a column are not significantly different at the 95% confidence level.

Table 3
Hedonic test[a] of composite breads.

Composite breads[b]	Overall acceptance	Crumb colour	Crumb appearence	Texture	Taste
30% yam starch (*D. Cayenensis-rotundata*)	6.34ab	6.26a	6.69a	6.26a	6.33ab
40% yam starch (*D. Cayenensis-rotundata*)	5.85b	6.14a	6.40a	5.50ab	5.78bc
20% cassava starch (*Manihot esculenta C.*)	6.28ab	6.33a	6.38a	5.92ab	6.21abc
30% cassava starch (*Manihot esculenta C.*)	5.83b	5.88a	5.30b	5.40b	5.61c
100% white wheat flour (*Triticum eastivum*)	6.54a	6.50a	6.47a	6.14ab	6.57a

[a] Within the same column, the values followed by different letters differ significantly (Duncan's multiple range test, $p < 0.05$). These values are the means of scores ranging from 1 represented "dislike extremely" to 9 represented "like extremely".
[b] The percentages are the levels of white wheat flour substitutions for yam or cassava starch.

or wheat bran flour, the more the volume of the resulted breads decreased (Fig. 3c and d). Specifically, Table 2 shows that yam starch-enriched breads with 10–40% of substitution and cassava starch-enriched breads with 10–30% of substitution gave loaves as bulky as the refined wheat bread. Beyond these concentrations, the resulting breads were less voluminous, leading to greater specific weights (Table 2). For C*Actistar or wheat bran enriched breads, all formulations resulted in loaves which were less bulky and more heavy than the control. The specific weights of the resulted breads, calculated as a ratio of loaf mass/volume, increased with the substitution of refined wheat for wheat bran or C*Actistar (Table 2). A series of physical, chemical and biological changes such as evaporation of water, formation of porous structure, volume expansion, protein denaturation, starch gelatinization, crust formation etc. take place during bread baking. However, the rheological changes in heated dough are essentially due to changes in the starch fraction (starch gelatinization), which dramatically increases dough viscosity and solid-like behavior (Peressini, Sensidoni, Pollini, & de Cindio, 1999). According to Wagner, Lucas, Le Ray, & Trystram (2007), the temperatures in the top and bottom regions of bread loaves increased, whereas the temperatures in the core region did not exceed 60–65 °C during the first 7 min of bread baking. On the other hand, some authors asserted that in the centre of the bread, the temperature increased slowly reaching 100 °C, after 8 min baking (Primo-Martin, van Nieuwenhuijzen, Hamer, & van Vliet, 2007). In all cases, such temperatures are often reported as the onset of starch gelatinization or over (Bloksma, 1990; Engelsen, Jensen, Pedersen, Norgaard, & Munck, 2001; Zanoni, Peri, & Bruno, 1995). At these temperatures, white wheat flour, wheat bran flour, yam and cassava starches underwent the gelatinization (Table 1), and for the blended forms, the swelling of their starches contributed to bread expansion. When the added fraction of flour blends increased, especially with yam or cassava starch, the dough gelatinization was delayed, due to the greater gelatinization temperatures of these starches, compared to that of the white wheat flour (Table 1). The expansion of the composite breads decreased, while increased the substitution of white wheat flour. As for the composite doughs containing wheat bran, the swelling extents were reduced (Table 2), due to a lower starch content provided by the wheat bran fraction (Table 1) or the competition for water uptake between fibres and starch, during baking. Moreover, composite doughs made from C*Actistar starch did not gelatinize or gelatinized to a lesser extent, during the bread baking, because their onset temperatures of gelatinization were higher than 100 °C (Table 1). The resulted bread expanded less, as the C*Actistar starch fraction increased (Table 2).

3.5. Sensory evaluation

Two formulations of yam starch or cassava starch enriched bread, with the highest added fraction, leading to bread loaves as bulky as that of the control, were used for the hedonic tests. They were the 30% and 40% added yam starch, and the 20% and 30% added cassava starch (Table 2). Table 3 shows that 30% yam starch substitution and 20% added cassava starch led to composite breads which satisfied the consumer expectations for all attributes, as the control. At concentrations higher than these promising formulations, some bread attributes became less pleasant. When yam substitution was 40%, the fall of the overall acceptance of the resulted bread was explained by a decrease in taste. Other authors, using yam flour in composite bread-making, found lower levels of satisfying yam flour added. According to Ukpabi (2010), wheat-lesser yam composite flour at the ratio of 80:20 (w/w) could be used for the production of bread that is comparable to those made with sole wheat bread flour in Nigeria. The satisfying substitution level for yam starch used in composite bread-making, in the present study, seems higher than that of yam flour, probably due to the advantage of a greater purity of starch form, in comparison with flour form. No previous studies, using yam starch as enriching agent in bread-making, have been performed before this present work. Concerning cassava starch, it has been found that a substitution of refined wheat flour for 30% cassava starch decreased the overall acceptance, due to a lesser pleasant crumb appearance, texture and taste. In our study, 20% cassava starch enriched bread was found as the optimum formulation. Similar findings have been reported by Aboaba and Obakpolor (2010), suggesting that sensory evaluation results showed that the bread containing 10 and 20% cassava flour was acceptable judging by all parameters used. According to these authors, those with 30 and 40% were not acceptable by the panelists, because the size, colour of the crust, loaf texture and taste were most undesirable. Another study on wheat/cassava composite flour bread revealed that the results for 10 and 20% substituted breads were comparable to that of the control (Eddy et al., 2007). According to these authors, above these levels of substitution, hedonic sensory attributes were depreciated. Other starchy plants have been used to substitute white wheat flour in bread-making. Thus, according to Balla et al. (1999), up to 30% sorghum flour could substitute refined wheat flour, with no significant impairment of resulted bread attributes, while Ade-Omowaye, Akinwande, Bolarinwa, and Adebiyi (2008) produced bread from 10% tigernut flour and 90% wheat flour, and Shittu et al. (2007) from 10% cassava and 90% wheat flour.

4. Conclusions

From the overall results, it could be concluded that the addition of yam or cassava starch to wheat flour modifies to a lesser or greater extent, rheological properties of the dough, depending on the botanical source of the starch and the level of white wheat flour substitution. On the basis of dough loaves expansion and consumer's acceptance of resulted bread, the optimums of starch blended with refined wheat flour, for composite bread-making, were up to 30% yam starch and up to 20% cassava starch. Above 30% added yam starch, the taste of the resulted bread impaired overall acceptance of the product. For cassava starch enriched bread, a substitution beyond 20% cassava starch gave an unpleasant crumb appearance and a disliked texture and taste to the bread. This study showed that the main roots and tubers produced in Africa, cassava and yam plants, could be valorized as starch-enriching agents in bread-making, and may represent a substitute ingredient to overcome the usual rising price of wheat on the world market. An investigation on nutritional benefits of these native starches, notably yam starch, as resistant starch in bread-making, would be interesting.

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