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Review

Risk of exposures of pesticide residues from tomato in Tanzania

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Tomato contributes the highest percent to the fruit and vegetables consumed in Tanzania. Its high consumption is attributed to the presence of bioactive compounds and vitamins known to prevent non-communicable diseases. Pesticides used to control pests and diseases cause direct accumulation of pesticide residues in food. Consumption of pesticide contaminated tomato increases the risk of pesticide exposure. This review is on types of pesticides used in tomato production, health effects of pesticides, levels of pesticide residues in tomatoes, dietary pesticide exposure, awareness on pesticides effects and preventive measures as well as policies governing pesticide use in Tanzania. Clearly, there is evidence of extensive use of pesticides in tomato production, limited knowledge regarding pesticide use, as well as weak regulatory framework for pesticide use. Importantly, levels of pesticide residues in tomatoes consumed in Tanzania exceed the recommended maximum residual limits. In order to assure pesticide safety of food, there is a need to identify and control farmers' practices which are highly associated with pesticide contamination in tomatoes.

Key words: Contamination, exposure, pesticide, residues, tomato.

INTRODUCTION

Tanzania's economy is highly dependent on agriculture, which accounts for 26% of the gross domestic product (GDP) and about two-thirds of the total exports. Tomato (*Solanum lycopersicum)* is the single most dominant vegetable crop which contributes the highest percentage (63%) of all annually harvested fruits and vegetables in Tanzania (Ministry of Agriculture Food Security and Cooperatives, 2012; Putter et al., 2007). A survey done by Match-Maker-Associates-Limited (MMA, 2008) shows that, tomato production in Tanzania is basically in the temperate areas including Southern and Northern highlands. According to MMA (2008) and Mushobozi (2010), among regions cultivating tomatoes, Morogoro has the largest area of about 2,442 ha (9.2% of its land), followed by Kagera (2386 ha, 9%), Tanga (2,326 ha, 8.7%), Mwanza (2,235 ha, 8.4%) and Iringa (2,223 ha, 8.4%). The biggest markets for tomato are urban areas including Dar es Salaam, Mbeya, Moshi and Arusha

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(MMA, 2008; MUVI-SIDO, 2009). Muunganisho wa Ujasiriamali Vijijini- Small Industry Development Organization (MUVI-SIDO, 2009) reported that, in Tanzania, tomatoes are consumed as fresh, cooked or processed into various products including sauce, ketchup, chutney, jam and base of other sauces.

Tomatoes contain bioactive compounds including carotenoids and vitamin A, B, C and E which lower the risk of non-communicable diseases (NCD) (Canene-Adams et al., 2005; Frusciante et al., 2007; Ibitayo and Monosson, 2007; MUVI-SIDO, 2009; Raffo et al., 2002; Smith and Eyzaguirre, 2007). Polyphenolic compounds in tomatoes act as free radical scavengers and possess therapeutic power for inflammatory and cardiovascular diseases, obesity, type II diabetes, cancer, neurodegenerative diseases, and aging (Frusciante et al., 2007; Raiola et al., 2014). These beneficial effects increase importance of tomatoes to be a component of daily diets.

Over 50% of global agriculture products is lost prior to or following harvest as a consequence of pests, diseases and weeds (Mushobozi, 2010). It is estimated that, in Tanzania, about 31% of tomatoes is lost due to pest and diseases (MMA, 2008). Farmers use different pesticides to minimize crop loss and increase production to meet the demand of the increasing world population (Hossain et al., 2013). Insecticides are the most common pesticides used in Tanzania for the treatment of 770,036 ha or 71% of the total planted area, followed by herbicides (203, 175 and 19%), and fungicides (105,124, 10%) (Nonga et al., 2011). It has been reported that, there is extensive use of pesticides in tomato production in Morogoro, Manyara and Arusha regions (Busindi, 2012; Ngowi et al., 2007; Nonga et al., 2011). This extensive use is caused by farmers failure to interpret labelling languages and lack of agriculture trainings or extension services (Mdegela et al., 2013; Ngowi et al., 2007). Farmers apply pesticides in mixtures (Ngowi et al., 2007) and use lambda cyhalothrin (karate) every seven days instead of fourteen days and one day instead of seven days before harvesting (Busindi, 2012). Application of pesticides in a mixture can induce phytotoxicity in tomatoes as a result of interaction between/among the pesticide types (Smit et al., 2002). Most of the pesticide residues from vegetable fields have been detected in soil and irrigation water in Ngarenanyuki and Uwiro estate; the key tomato production area in Arusha region (Kihampa et al., 2010a, b). Improper use of pesticides causes accumulation of residues in foods which decreases the safety and quality of food products and ultimately results in serious health problems (Al-Waili et al., 2012; Dewhurst and Marrs 2009; Kihampa et al., 2010a; Ntow et al., 2006). The most real risk is posed by consumption of fresh food as vegetables and fruits as these have higher levels of residues as compared to processed or semi processed food products (Baig et al., 2009; Price, 2008; Solecki et al., 2005). In Tanzania, tomato processing industry is poorly developed (MUVI-SIDO, 2009). This makes most of the grown tomatoes to be sold as fresh form.

This paper is a review on types of pesticides used in tomato production, health effects of pesticides, levels of pesticide residues in tomatoes, dietary exposure of pesticide, awareness on pesticides effects and preventive measures as well as policies governing pesticides use in Tanzania.

PESTICIDES USED IN TOMATO PRODUCTION

Diseases and pests remain the biggest problem in tomato production in Tanzania (Engindeniz, 2006; Mushobozi, 2010). Some important pests of vegetable crops are whitefly, aphids, thrips, leaf hoppers, caterpillars, mites and nematodes (Mushobozi, 2010; Sithanantham et al., 2002). Whiteflies, moth, cutworms, bollworms, wireworms and aphids are the frequent insect pests in tomatoes, while the acar and fungus pests include mites and bacterial spot, fusarium wilt, early blight, and downy mildew, respectively (Engindeniz, 2006; Mushobozi, 2010; Sithanantham et al., 2002). Table 1 shows the key pest and disease problems in tomatoes, requiring the use of pesticides. The problems are rated for their importance to the effect on crop yield and pesticide residues. Integrated pest management (IPM) requires that pesticides are used as the last solution and after their effectiveness and non-hazardous nature to the environment have been proven (Mushobozi, 2010).

Pesticides are classified according to their chemical classes such as organochlorines, and organophosphates; or based on their target action such as acaricides, herbicides or insecticides; or by their biochemical mode of action (MoA) (Tsipi et al., 2015).

In Tanzania, pesticides are regulated according to the Plant Protection Act (No 13) of 1997 and the Plant Protection Regulations of 1999 which require all pesticides to be registered before sale and use. Pesticide registration is a regulatory requirement which involves scientific process to examine the physical and chemical properties of the pesticide, its effectiveness, and likelihood of causing hazard to human health and environment (Damalas and Eleftherohorinos, 2011; Mushobozi, 2010). The body responsible for registration of pesticides in Tanzania is the Tropical Pesticide Research Institution (TPRI). Some pesticides registered by TPRI for use in tomato and other vegetables in Tanzania are chlorpyrifos, dioctyl sodium succinate, deltamethrin, dimethoate, fastac,alphacypermethrin, fenvalerate, lambda cyhalothrin, azadirachtin, copper hydroxide, mancozeb, folpet and carbofuran (TPRI, 2007). As of 2013, the active ingredients for most of these pesticides are gramoxone against weeds,

Table 1. Key pest or disease problems and their importance to tomato yield or pesticide residues.

Problem	Species name	Importance		Description
		Tomato yield	Pesticide residue	
Foliar pests				
Spider mites	*Tetranychus urticae*	***	**	Causes severe leaf damage and loss of yield
Glasshouse whitefly	*Trialeurodes vaporariorum*	***	*	Feed on leaves and cause leaves damage as well as cause sooty moulds on fruit.
Tomato leaf miner	*Liriomyza bryoniae*	**	*	Causes leaf damage.
Mealy bugs	*Pseudococcus viburni*	**	*	Cause leaf loss and sooty moulds.
Macrolophus	*Macrolophus caliginosus*.	**	*	Feed on young fruit and cause fruit damage.
Foliar/stem/root diseases				
Grey mould	*Botrytis cinerea*	***	**	Attacks all aerial parts of the plant and causes 'ghost-spotting' on fruit
Powdery mildew	*Oidium neolycopersici*.	**	*	Attacks leaves, stems and calyces
Verticillium wilt	*Verticillium alboatrum*	**	-	Causes leaf wilt and stem collapse.
Root rots	*Pythium, Phytophthora* and *Rhizoctonia solani*	*	-	Causes reduction in plant vigour and may cause plant collapse and death

*** = High: ** = medium: * = low: - = no importance because associated pesticides were not found or sought. Source: Caspell et al., 2006.

cypermethrine and dimethoate against insects, and metalaxyl, maneb, mancozeb and manizan against fungi (Abang et al., 2013).

The selection and application of pesticides is governed by Good Agricultural Practices (GAPs) promoted by the Ministry of Agriculture, Livestock and Fisheries in Tanzania (Larcher, 2005). Application of GAPs may reduce the risk of exposure to pesticide to some extent. However, absolute avoidance of pesticide residues is not possible even when pesticides are used in accordance with GAPs (Essumang et al., 2008).

Health effects of pesticides

All pesticides can be harmful, but the levels of toxicity vary from pesticide to pesticide. The levels of danger are defined as Ia (extremely hazardous), IIb (highly hazardous), II (moderately hazardous), III (slightly hazardous), or unclassified and normally marked on the pesticide label by colour code or as hazard classification (WHO, 2010). Pesticide toxicity occurs when chemicals intended to control a pest affect non-target organisms such as human beings. The toxicity occurs in three forms which are single short-term very high level of exposure (acute toxicity), long-term high-level exposure and long-term low-level exposure (Gupta, 2011; Hamilton ad Crossley, 2004; Owen and Pickering, 2006). Long-term low-level exposure or chronic toxicity is linked with pesticide residues in food as well as contact with pesticide residues in the air, water, soil, sediment, food materials, plants and animals (Gupta, 2011; Hamilton and Crossley, 2004; Owen and Pickering, 2006). Acute toxicity explains how poisonous a pesticide is to a human, animal, or plant after a single short-term exposure. The effects of acute toxicity appear quickly, or within 24 h of exposure. Acute toxicity can be measured as acute oral toxicity, dermal toxicity and inhalation toxicity. According to Pesticide Safety Education Program (PSEP, 2012) and Kamel and Hoppin (2004), toxicity is the basis for levels warning statements on the pesticide container label. Chronic toxicity is a concern for general public as well as those who work directly with pesticides. It involves pesticide exposure through food, water and air normally determined after three months of either continuous or occasional exposure (Barrett, 2005; PSEP, 2012).

Pesticide poisoning causes mortality and morbidity throughout the world particularly in developing countries (Litchfield, 2005) due to the lack of suitable national Maximum Residual Limits (MRLs), overlapping mandates, complex label instruction, limited trainings in pesticide application procedures or hazard awareness in addition to unwillingness of manufacturers to generate new data for crops of importance to these countries (Agriculture-Consumer-Protection, 2001)

The nature of pesticide toxicity cannot be changed but measures can be taken to prevent the possibility of poisoning and controlling exposure. In other words, the risk of harm from pesticide exposure is equal to how poisonous the pesticide is, multiplied by the amount and route of exposure to the pesticide (PSEP, 2012).

Pesticide effects on the body depend on the length and magnitude of exposure; and toxicity of the chemical. Higher consumers of pesticide contaminated tomatoes have the greatest exposure to these pesticides. Increased risk for health outcomes is higher during a critical period of development, such as conception to puberty (Weselak et al., 2007). Effects of pesticides ranges from mild skin irritation to birth defects, tumours, genetic changes, blood and nerve disorders, endocrine disruption, and even coma or death (Hong-Sheng Wang et al., 2011; Tebourbi et al., 2011). It also affects reproductive, endocrine and immune systems. Chronic exposure causes infertility, neurobehavioral disorder, diseases such as cancer and mutagenic effects (Al-Waili et al., 2012).

In Tanzania, farmers have been affected by direct pesticide exposures which are linked with lack of protective gears. The health effects observed were headache, stomach ache, chest pain, skin and eye irritation, difficulty in breathing as well as nausea and vomiting (Mdegela et al., 2013; Ngowi et al., 2007). There is limited information on health effects associated with pesticide dietary exposure from pesticide contaminated foods in Tanzania, hence efforts need to be taken to generate such information. The only available information was generated by Kariathi et al. (2016) whereby they investigated pesticide exposure from fresh tomatoes.

Intensive application of pesticides affects, in addition to human health, the environment due to residues that remain in different environmental matrices as well as water and air (Mekonen et al., 2014). In Tanzania, pesticide residues were detected in the samples of irrigation water for which frequency of detection was increased for samples collected downstream in the fields as well as in fresh tomatoes (Kihampa et al., 2010b). Despite the established evidence of intensive use of pesticide in tomato production, detectable amount of residues and proven risk of pesticide dietary exposure, there is limited information on the pesticide residual levels from other food products and their associated health risks to consumers in Tanzania.

Dietary exposure of pesticides

Human exposure to pesticides and their metabolites occurs via ingestion of contaminated food, inhalation, across the placenta or dermal contact (Gilden et al., 2010). In the food chain, the exposure is direct, through the consumption of treated foods, or indirect, through the transfer of residues into products of animal origin from treated feed items (Tsipi et al., 2015). Dietary exposure from the ingestion of contaminated food is the primary route of exposure of most pesticides and is the route of exposure for the general population (Aktar et al., 2009; Dougherty et al., 2000; Gilden et al., 2010; Matthews, 2006; Oates and Cohen, 2011). Consumption of pesticide active ingredients through food ingestion has been shown to be up to five times higher than other exposure routes like ingestion of drinking water and air inhalation. Fresh food consumption bring serious problems as they are expected to contain higher pesticide residue levels than other food groups (Pavel et al., 2013; Pogăcean et al., 2013; Solecki et al., 2005). This implies that consumers have to be guided in terms of how to choose pesticide free tomatoes or process them to reduce contamination.

Pesticide residues levels in tomatoes

The need for intensive use of pesticides in horticultural crops means that farmers have to be knowledgeable on how to apply them. However, it has been confirmed that pesticide application knowledge is very limited amongst farmers in Tanzania. Ngowi (2002) reported that, farmers in East Africa use hazardous pesticides though most of the pesticides approved for use in Tanzania are reducing in the level II which is moderately hazardous (Nonga et al., 2011). Also, vegetable farmers in the Northern zone of Tanzania, lack appropriate knowledge and skills of safe pesticide handling and use (Ngowi et al., 2007). The poor knowledge is evidenced by farmers practice of applying different formulations so as to cure serious pest problems (Ngowi et al., 2007). Additionally, farmers are not aware of authorized maximum residue limits for pesticides in food, approved and prohibited substances, acceptable dose level, choice of pesticides, restrictions on use and pre-harvest interval (PHI) (Mushobozi, 2010; Sithanantham et al., 2002). The involvement of extension services in pesticide application is thus crucial (ESRF, 2010).

The limited knowledge on pesticide application and awareness of pesticide impacts on human health causes unacceptable levels of pesticide residues in foods. In the survey of pesticide residue in Cameroon, fresh tomato was one of the products for which at least one result had greater than the limit of detection (LOD) among the locally produced foods (Gimou et al., 2008). Tables 2 and 3 show pesticide residues in tomatoes in some European, and African countries including Tanzania. In these tables, tomatoes from both European and African countries have detectable pesticide residues and some have even exceeded the MRL which might pose health risks to consumers.

Effects of processing on pesticide content in food

Good agricultural practices (GAP) and good manufacturing practices (GMP) are very crucial in lowering the risks associated with pesticides exposure in tomatoes if observed. In most areas with intensive use of

Table 2. Pesticide residues above the legal limit reported in tomatoes from European and Asian countries.

Country	Pesticide	Residue(mg/kg)	[1]MRL (mg/kg)	Reference
Italy	Chlormequat	0.20	0.05	PAN-UK (2006)
Italy	Chlormequat	0.07	0.05	
Spain	Chlormequat	1.50	0.05	

[1]MRL- Maximum residue limit.

Table 3. Pesticide residue levels in tomatoes from some African countries.

Country	Pesticide	Mean residue (mg/kg)	MRL (mg/kg)	Reference
Nigeria	p,p'-DDE	0.058±0.0110	0.1	Benson and Olufunke (2011)
	p,p'-DDD	0.086±0.086	0.1	
	p,p'-DDT	0.046±0.010	0.1	
Ghana	Chlorpyrifos	0.046±0.01	0.5	Bempah et al. (2012)
	Cypermethrin	0.035±0.005	0.5	
	Permethrin	0.015±0.015	0.05	
	p,p'-DDE	0.013±0.009	0.05	
	p,p'-DDT	0.012± 0.006	0.05	
	Fenvalerate	0.014±0.008	0.1	
	Diazinon	0.009±0.003	0.5	
	Dimethoate	0.013±0.009	0.02	
	P-methyl	0.017±0.007	0.2	
	Malathion	0.038±0.032	3.0	
Egypt	Fenpropathrin	0.080±0.01	0.01	Ahmed et al. (2014)
	L-Cyhalothrin	0.070±0.01	0.1	
	Ethion	0.270±0.005	0.01	
	Malathion	0.025±0.005	0.5	
	Chlorfenapyr	0.030±0.01	0.05	
	Profenofos	0.181±0.01	0.05	
Tanzania	Chlorpyrifos	7.528	1.0	Kariathi et al., (2016)
	Permethrin	5.289	1.0	
	Ridomil	2,854.729	0.5	

DDE = Dichloro-diphenyldichlorethylene, DDD = dichloro-diphenyldichlorethane, DDT = dichloro-diphenyltrichloroethane, L = Lambda, P = Pirimiphos.

pesticides, food safety has become a major public health concern (Aktar et al., 2009). Household tomato processing such as washing and peeling may reduce pesticide residues to some extent (Kwon et al., 2015) though they are unable to clear all pesticides. Tomato drying and boiling to produce jam and paste are commonly industrial processing technologies in Tanzania (MUVI-SIDO, 2009) which tend to increase pesticide residues due to evaporation which concentrate pesticides (Kwon et al., 2015). Since tomato processing technologies in Tanzania are poorly developed and are not capable of reducing pesticide residues in tomatoes, an assessment on the extent of pesticide contamination as well as the consumption pattern for tomatoes in order to be able to advice on appropriate preventive measures against exposure of pesticides in Tanzania is recommended.

Consumers' awareness on pesticides effects and preventive measures

In European countries, consumers are anxious about the pesticide residues in their food and want to avoid them as

much as possible (Keikotlhaile and Spanoghe, 2011; Petersen and Jensen, 2012). In Turkey and possibly other countries, consumers are also willing to pay a higher price for slightly damaged vegetables because it is clear that the use of pesticides was low, and so residues are low (Engindeniz, 2006). In a study conducted in Nairobi-Kenya by Ngigi et al. (2010), it was observed that consumers purchase fresh vegetables in supermarkets and specialty stores because they perceive vegetables sold in such stores are safer than those in the wet markets. As in other countries around the world, consumers in Tanzania are willing to pay premium for pesticide free tomatoes and choose organic and inspected products to be free from pesticide residues (Alphonce and Alfnes, 2012). This observations show the importance of formulating and implementing measures that can assure the consumers that tomatoes from Tanzania are free of unacceptable pesticide residual levels.

REGULATION OF PESTICIDE RESIDUES IN FOODS

Generally, pesticide contamination in tomato occurs during production, post-harvest handling or other unit operations (Mushobozi, 2010). Tomatoes are highly targeted in chemical treatment against pests than other vegetables (Abang et al., 2013; Mdegela et al., 2013) and there is a high risk for presence of residues at levels that exceed the MRL. The MRL for most registered pesticides used in Tanzania ranges from 0.2 to 5 mg/kg for tomatoes (Codex, 2013). Levels above MRLs occur when GAPs or post-harvest preventive measures are not followed. Non-observance of GAPs can include the use of non-approved protocols linked to wrong pesticide selection, incorrect dosage, poor observation of harvesting interval, wrong calibration of sprayer, inadequate cleaning between uses as well as contamination of produce due to pesticide storage conditions (Al-Waili et al., 2012; Mushobozi, 2010).

The Tanzania Food and Drug Authority (TFDA) is responsible for protecting consumers against the consumption of unsafe food products. It regulates both imported and domestically produced foods by enforcing Tanzania Food, Drugs and Cosmetics Act (No 1) of 2003. The major challenge is enforcement of MRLs as most of tomatoes are consumed fresh and sold in informal market. There is a need for a risk assessment which will advise on the level of pesticide exposure through the informal sector tomatoes.

CONCLUSIONS

Farmers in Tanzania apply pesticides intensively in tomato production because the crop is highly susceptible to infestation and diseases. Available reports show that most farmers in Tanzania are unaware of good practices for pesticide application. Based on these reports, there is evidence that, tomatoes grown and consumed in Tanzania contain pesticide residues at levels that can harm the consumers. In view of the worries, there is an urgent need to generate more data on levels of pesticide residues in tomato and other food products from Tanzania and use the data to perform a risk assessment to estimate the risk of exposure of pesticide residues in Tanzania. The outcome of the exposure assessment and those of the recent assessment by Kariathi et al. (2016) can be used in advising the government on strategies that can be employed to prevent improper application of pesticides in food production and protect the general public from exposure of pesticides. These will ensure permanent access to safe food products by all the consumers and protect them from health effects of pesticides.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest.

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Effect of blending ginger starch (*Zingiber officinale*) on the dynamic rheological, pasting and textural properties of rice flour

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Rice flour (RF) was blended with ginger starch (GS) (*Zingiber officinale*) at various concentration levels (0, 20, 40, 60, 80 and 100%) and compared with that of cassava starch (CaS). The dynamic rheological, pasting and textural property effects of these starches on RF were studied. CaS and GS and their blends with RF all exhibited a weak gel behavior as shown by their dynamic moduli (G' and G") values. The higher tan δ (0.45 and 0.51) values recorded by GS and CaS respectively raised the tan δ values in their blends with RF thereby reducing the elasticity of RF. The rapid visco analyzer (RVA) results revealed that, GS exhibited the appropriate characteristics for noodle processing in most of the pasting properties as compared to CaS such as; higher trough viscosity (165.05 RVU), final viscosity (241.20 RVU) and lower swelling power (13.17 g/g). CaS gets to be selected over GS for energy conservation during cooking since it recorded a lower pasting temperature of 70.90°C likewise its formulated blends with RF. Measurement of textural property demonstrated that, the hardness and chewiness of RF could be increased (101.25-293.34 g and 47.34-72.19) respectively by blending with GS. Also, the cohesiveness of RF got to be reduced (0.51-0.27) by the addition of GS. The various properties of GS and its effect on RF blends unveiled in this study makes GS fit to be considered in the modification of rice flour for noodle production.

Key words: Rice flour, ginger starch, cassava starch, formulated blends, physiochemical properties.

INTRODUCTION

Rice flour is one of the basic ingredients in the production of various food products. However, rice noodles stand out to be the most favorably consumed by many people in South Asian countries, and China is no exception (Qazi et al., 2014). Apart from the variations in the technology of production, instability of the quality of rice being the raw materials used also adds to the drawbacks on the noodle product's qualities (Surojanametakul et al., 2002).

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The structural network of noodle products is mainly determined by the starch content of the rice noodle due to the absence of gluten in rice flour (Yoenyonbuddhagal and Noomhorm, 2002; Qazi et al., 2014). Therefore, combination of different starches have been used for noodles preparation, such as corn and potato starches, maize and tapioca starches (Kasemsuwan et al., 1998; Kaur et al., 2005) respectively. The replacement of rice flour with various starches such as cassava starch, potato starch and corn starch had various characteristics upon the type/amount of starch added (Surojanametakul et al., 2002). Since starch from different plant source varies in appearance, composition, as well as properties, due to its morphology and physiochemical properties, there is the need to continue the search for starch with excellent properties from both conventional and non-conventional sources (Kolawole et al., 2013). Blending of various tropical crop starches such as canna starch, mung bean starch, sweet potato starch, cassava starch, corn starch with rice flour has been studied (Surojanametakul et al., 2002; Thao and Noomhorm, 2012; Qazi et al., 2014). However, starches obtained from many tubers and roots, with few exceptions such as, arrowroot, and ginger have not been commercialized (Peroni et al., 2006). Ginger root (*Zingiber officinale*) is mostly consumed as a delicacy, medicine or spice as well as used in phytotherapy because of its volatile oil and oleoresin. A powdery substance was extracted from ginger roots and upon the physiochemical test performed confirmed the presence of carbohydrate that means starch (Talele et al., 2015). Extraction of ginger starch has received various research attentions (Talele et al., 2015). Also, there are studies on the modification of cassava starch with ginger (Daramola and Osanyinlusi 2006). Ginger starch also compared favorably with maize starch as in physiochemical properties and therefore showed that it has a high potential for industrial applications as biomaterials in composites food, textile and pharmaceutical industries (Afolayan et al., 2014). According to a report by Peroni et al. (2006), ginger starch displayed a higher amylose content of 26.5% and therefore makes it fit to be considered in the production of noodles since amylose content of starch/flour used in noodle production has a significant correlation with the noodles quality. However, studies on its applications in the food industry is extensively limited, especially, its use in the modification of rice flour for noodle production. Hence, the need to study and compare its physiochemical effect on the properties of rice flour with that of cassava starch which is already in use. The color, water binding capacity, swelling power and solubility, pasting, textural and dynamic rheological properties of pure rice flour (RF), native cassava starch (CaS), native ginger starch (GS) and the formulated blends were studied. The objective of this research work was to find out whether ginger starch is fit to be used in rice flour modification for noodle production as cassava and other tropical crop starches are already commercialized.

MATERIALS AND METHODS

Commercial native cassava starch (CaS) and sticky milled rice flour (RF) were purchased from Nanjing Ganzhiyuan Sugar Co LTD and Cho Heng Rice Vermicelli factory Co. Ltd (China) respectively. Fresh ginger (*Z. officinale*) was bought from an open market in Changsha City, Hunan province of China and other analytical grade reagents were obtained from Yueyang Hunan Chemical Industry Co. Ltd (China).

Isolation of starch from Ginger (*Z. officinale*)

Native ginger starch extraction was carried out according to the method described by Kolawole et al. (2013) with little modification for larger quantity. Fresh roots of ginger of about 4 kg were peeled and washed. The samples were cut into small pieces and soaked in 4 L of 1% w/v sodium metabisulphite solution at room temperature (25°C overnight (24 h) to aid the release of starch. The pieces of root were removed and wet milled into a slurry using a grater. The paste was dispersed in large volume of 1% w/v sodium metabisulphite solution and filtered through muslin cheese cloth. The filtrate was allowed to stand for 1 h to facilitate starch sedimentation and the top was decanted and discarded. The starch was washed with 2 L of 1% w/v sodium metabisulphite solution and then, the suspension was centrifuged at 3500 rpm for 10 min to facilitate the removal of dirt. The supernatant was carefully decanted and the mucilage scraped off, the process was repeated for five times with the mucilage on the starch scraped continuously until a pure starch was obtained. The resulting starch was dried at 60°C in hot air oven, dry milled, sieved through 80 mesh sieve, weighed and packed in airtight polythene bags then stored in the refrigerator at 4°C.

Proximate analysis of rice flour

The moisture, ash, protein, fat, total sugar and starch contents of rice flour were determined according to methods described in American Association of Cereal Chemists (AACC, 2000).

Blends formulations

Rice flour was blended manually with cassava and ginger starches at ratio levels of 100:0, 80:20, 60:40, 40:60, 20:80 and 0:100 (weight basis) and were sieved using 80 mesh sieve in order to obtain granules of uniform sizes. They were packed into an airtight polythene bags and stored in the refrigerator at 4°C until used. The blends of RF and starches were studied for water binding capacity (WBC), swelling power (SP) and solubility (S), pasting, textural and dynamic rheological properties.

Color measurements

The color L* (index of lightness/darkness), a* (index of hue, red/green) and b* (index of hue, yellow/blue) where, L* = lightness (0 = black, 100 = white), a* (-a* = greenness, +a* = redness) and b* (-b* = blueness, +b* = yellowness of pure rice flour (RF), ginger starch (GS) and cassava starch (CaS) were determined using

Chroma meter, CR-400 from Konica Minolta Sensing, INC. (Industrial Instruments), Japan. Three repeated measurements were taken for each of the three replicate (starch/flour) per sample (total of nine readings per sample). The whiteness value was obtained according to Equation (1).

$$\text{Whiteness} = 100 - [(100 - L)^2 + a^2 + b^2]^{\frac{1}{2}} \quad (1)$$

Water binding capacity

Water binding capacity was determined according to the method proposed by Oke et al. (2013). About 2.5 g of the samples (rice flour and starch formulation) was suspendered in 30 ml distilled water at 30°C in a centrifuging tube, shook for 30 min using a water bathing constant temperature vibrator and then, centrifuged at 3000 rpm for 10 min. The supernatant was decanted and the weight of the paste formed was recorded. The water binding capacity (WBC) was then calculated as the paste weight per gram dry sample.

$$\text{WBC} = \frac{\text{Gram bound water}}{\text{weight of dry sample(g)}} \times 100 \quad (2)$$

Determination of swelling power and solubility

Swelling power and solubility of pure rice flour and starches were measured using the method described by Oke et al. (2013) with little modification. Dry sample of 0.5 g was weighed in triplicate and then transferred to a 100 ml conical flask. Exactly 15 ml of distilled water was added and stirred. The sample was transferred into a water bathing constant temperature vibrator then, heated for 30 min at 92.5°C with constant shaking (stiring). The gel formed was transferred into pre-weighed centrifuge tubes and centrifuged at 3500 rpm for 15 min. The supernatant was then carefully poured into pre-weighed petri dishes and the gel sediments in the centrifuge tubes were weighed. The supernatant in the petri dish were evaporated at 130°C for 8 h and weighed again. Swelling power was expressed in g of swollen granules per g of dry starch/flour in the sediments and solubility (%) was expressed as the weight of soluble starch/flour in percent of initial dry starch weight. SP and S were calculated according to Equations 3 and 4.

$$S = \frac{weight\ of\ soluble\ starch/flour}{weight\ of\ sample\ on\ dry\ bases} \times 100 \quad (3)$$

$$SP = \frac{weight\ of\ sedimented\ paste}{weight\ of\ sample\ on\ dry\ bases \times (100 - S)} \times 100 \quad (4)$$

Pasting properties

Pasting properties of rice flour and starch formulations (at different concentrations) were determined according to AACC (2003), using a Rapid Visco Analyzer controlled by Thermocline software for windows (RVA, Model 4D, Newport Scientific, Australia). Sample (3.0 g, 14 g/100 g moisture basis, in triplicate) was weighed directly into the RVA canister and distilled water was added to obtain a total weight of 28 g. The samples were stirred by the paddle in the RVA canister at 960 rpm for the first 10 s then at 160 rpm for the rest of the test. There are five stages of the standard profile; (1) holding for 1 min at initial temperature (50°C), (2) heating to 95°C for over 3.42 min, (3) holding at 95°C for 2.3 min, (4) cooling to 50°C for over 3.48 min and (5) holding at 50°C for 2 min. Each sample was held for 13 min and the interval between viscosity and temperature readings was 4 s. Values measured from the pasting profile were, peak viscosity (PV), trough viscosity (TV), final viscosity (FV), peak time (P_{time}), pasting temperature (P_T) and breakdown. While relative break down, relative set back and pasting time were calculated from the data obtained by RVA using Equations 5 and 6.

$$RBD(\%) = \frac{Break\ down}{Peak\ viscosity} \times 100 \quad (5)$$

$$RSB(\%) = \frac{Set\ back}{Final\ viscosity} \times 100 \quad (6)$$

Texture analysis of RVA gels

Texture analysis as reported by Bhattacharya et al. (1999) was followed with slight modification. The samples prepared in the RVA was poured into small aluminum canisters (37.0 mm diameter and 20.0 mm height) and stored at 2°C overnight for solid gel formation. The aluminum canisters were sealed with paraffin wrap to prevent moisture loss during storage. The solid gel formed was evaluated for their textural properties by texture profile analysis (TPA) using the texture analyzer (TA/XT2*i*, Stable MicroSystems, Surrey, UK) equipped with a Texture Expect Software program (version 5.16). Each canister was placed upright on a metal plate and the solid gel was compressed at a speed of 1.0 mm/s to a distance of 10 mm with a stainless steel punch probe (P/0.5). The compression was repeated twice to generate a force-time curve from which hardness (HD,g), springiness (SP,mm), adhesiveness (AD), cohesiveness (CO), gumminess (GU, g) (hardness × cohesiveness), chewiness (CH, g×mm) (gumminess×springiness) were all computed by the software supplied with the instrument. Three repeated measurements were taken for each of the three replicate gels per sample (total of nine readings per sample). The diameter of the solid gel (37 mm) was divided such that unbiased repeat measurements (with puncture) could be made on different areas of the same solid.

Rheological properties

The rheological properties of rice flour and starch formulations were determined using a rotational rheometer (Physical MCR 301, Anton Paar GmhH Stuttart, Germany) equipped with a cone and a plate geometry sensor (40 mm diameter, 1°cone angle and 0.098 mm gap). Gelatinized samples paste (6% RF:Starch, w/w) were prepared by using the RVA. The gelatinized sample was placed on the determination platform of the instrument and a thin layer of silicon oil was added to prevent water evaporation. The dynamic viscoelasticity was determined in triplicate for each sample.

Dynamic viscoelastic measurements

The dynamic viscoelastic measurements of storage modulus (G') and loss modulus (G") were evaluated by first running deformation sweeps at a constant frequency (10 rad/s) to determine the maximum deformation attainable by a sample in the linear viscoelastic range. Afterwards, by applying a constant strain (0.5%), which was within the range, a dynamic frequency sweep over a frequency range of 0.1 to 10 Hz was performed. The sample measurement temperature was kept constant at 25°C.

Statistical analysis

All experiments and analysis were performed in three replications. The data was subjected to statistical one-way ANOVA test and Duncan multiple range test (DMRT) to compare means at 0.05

Table 1. The color values of pure rice flour, native cassava and ginger starch.

Sample	L*	a*	b*	Whiteness
RF	96.65 ± 0.19^{b}	0.37 ± 0.02^{b}	2.52 ± 0.02^{b}	95.81 ± 0.14^{b}
CaS	97.19 ± 0.02^{a}	0.11± 0.01^{a}	1.71 ± 0.04^{c}	96.79 ± 0.04^{a}
GS	95.35 ± 0.24^{c}	-0.42± 0.04^{c}	3.61 ± 0.04^{a}	94.09± 0.17^{c}

Values represents mean of triplicate determinations ±SD. Different letters within columns represents significant differences ($p<0.05$). Rice flour (RF), cassava starch (CaS) and ginger starch (GS).

Table 2. Physiochemical properties of rice flour (RF), cassava and ginger starch and their formulated blends.

Sample	WBC (%)	SP (g/g)	S (%)
RF	94.40 ±0.40^{a}	10.83 ±0.15^{d}	9.47 ± 0.61^{e}
CaS	68.57 ±2.11^{f}	27.70 ±0.10^{a}	11.77±0.55^{abc}
GS	64.13 ±2.20^{g}	13.17 ± 0.31^{c}	12.40 ±1.06^{a}
RF:CaS (80:20)	89.27 ±1.91^{b}	13.13± 0.42^{c}	10.73± 0.61^{cde}
RF:CaS (60:40)	84.57 ±1.17^{c}	13.33 ±0.68^{c}	12.20 ±0.35^{ab}
RF:CaS (40:60)	78.03 ±1.00^{d}	19.30 ± 3.40^{b}	11.67±1.62^{abc}
RF:CaS (20:80)	70.47 ±1.60^{f}	20.10 ±1.70^{b}	7.80 ±0.40^{f}
RF:GS (80:20)	85.07 ±0.23^{c}	10.57 ± 0.42^{d}	9.93 ±0.61^{de}
RF:GS (60:40)	82.53 ±2.27^{c}	10.77 ±0.32^{d}	10.93 ±1.10^{bcd}
RF:GS (40:60)	74.00 ±2.43^{e}	11.80 ± 0.17^{cd}	12.20 ± 0.20^{ab}
RF:GS (20:80)	70.00 ±1.60^{f}	12.07± 0.32^{cd}	12.87± 0.50^{a}

RF, CaS, GS are rice flour, cassava starch and ginger starch respectively. Assays were performed in triplicate. Mean ± SD values superscripted by different letters are significantly different from each other ($p<0.05$). WBC = water binding capacity, SP = swelling power, S = solubility.

significant level.

RESULTS AND DISCUSSION

Color measurement

Most consumers use color as one of the important parameters to evaluate the quality of rice noodles (Asenstorfer et al., 2010; Thomas et al., 2013). According to the results (Table 1), RF and the two native starches selected had a white (lightness) color. However, there was a significant difference in their lightness values with CaS having highest (97.19) whilst the least lightness was recorded for GS (95.35). Both RF and CaS had a red shade whilst GS had a green shade. The two starches under study with the RF had a yellowish color with GS recording a high b* value of (3.61) while CaS having a lower yellowness with b* value (1.71). According to the statistical analysis conducted, all the three samples under study were significantly different ($p<0.05$) from each other as in L* and a* values. The b* values recorded similar significant difference among the three samples under study. Finally, the overall whiteness among the three samples were significantly different from each other, which would influence the overall color of the formulated blends hence affects the color of the noodles produced. Starches with high value for lightness and low value for chroma are mostly preferred for noodles production (Tan et al., 2009). Hence, CaS will be preferred over GS for noodle processing.

Water binding capacity (%), swelling power (g/g) and solubility (%) of RF, CaS, GS and their formulated blends

Table 2 shows the analysis of water binding capacity (WBC), swelling power (SP) and solubility (S). The water binding capacity analyzed results revealed a significant difference at $p<0.05$ among all the samples. The rank

Table 3. Pasting properties of Rice flour paste (RF), cassava starch (CaS) and ginger (GS) starch and their formulated blends.

Sample	PV (RVU)	TV (RVU)	RBD (RVU)	FV (RVU)	RSB (RVU)	P_{time} (min)	PT (℃)
RF	192.08 ± 0.69^{f}	138.00 ±5.32^{f}	28.15 ±3.01^{d}	288.83±3.12^{b}	52.22 ±1.59^{a}	6.87±0.07^{ab}	91.55±0.52^{a}
CaS	341.50±5.55^{a}	140.72±3.73^{ef}	58.80 ±0.43^{a}	231.36 ±5.58^{fg}	39.18 ±0.15^{d}	4.15 ± 0.04^{g}	70.90 ±0.09^{f}
GS	184.08 ±1.01^{g}	165.05 ±1.35^{b}	10.34 ±0.33^{gh}	241.20 ±1.85^{e}	31.56 ±1.06^{f}	6.34 ±0.12^{c}	88.73 ±0.45^{b}
RF:CaS (80:20)	227.36 ±1.20^{e}	183.92±0.87^{a}	19.11 ±0.41^{e}	317.78 ±2.51^{a}	42.12 ± 0.49^{c}	6.78 ±0.10^{b}	79.47 ±0.46^{c}
RF:CaS (60:40)	232.53 ±2.15^{d}	163.89±3.88^{b}	29.52 ±1.05^{d}	270.03 ±7.77^{c}	39.29 ± 0.90^{d}	6.04 ±0.08^{d}	73.37 ±0.03^{d}
RF:CaS (40:60)	254.31 ±3.05^{c}	146.86±0.81^{d}	42.28±0.58^{d}	237.17 ±1.20^{ef}	38.04 ±0.29^{d}	5.27 ±0.07^{e}	72.02 ±0.51^{e}
RF:CaS (20:80)	305.30 ± 0.48^{b}	145.30±0.87^{de}	52.41 ± 0.21^{b}	225.61 ±1.00^{g}	35.60 ±0.10^{e}	4.67 ±0.00^{f}	71.73 ±0.06^{e}
RF:GS (80:20)	169.78 ±1.73^{h}	144.61±4.09^{de}	14.83±1.60^{f}	262.42±2.57^{d}	44.88 ±2.10^{b}	6.78 ±0.10^{b}	89.20 ±0.00^{b}
RF:GS (60:40)	159.86 ±0.10^{i}	139.86±1.72^{ef}	12.51 ±1.12^{fg}	239.22 ±8.07^{ef}	41.51 ±2.13^{c}	6.36 ±0.10^{c}	89.23 ±0.06^{b}
RF:GS (40:60)	156.83 ±1.04^{i}	145.39±0.98^{de}	7.30 ±0.05^{h}	215.17 ±2.57^{h}	32.42 ±1.27^{f}	6.24 ±0.08^{c}	89.23 ±0.90^{b}
RF:GS (20:80)	158.61 ±0.92^{i}	156.08 ±1.05^{c}	1.53±0.32^{i}	225.36±6.05^{g}	30.56±1.40^{f}	6.96±0.08^{a}	88.45±0.78^{b}

All values are means of triplicate determination. Values having different letters within the same column are significantly different from each other ($p<0.05$). PV = peak viscosity; TV = trough viscosity, RBD = relative breakdown; FV = final viscosity; RSB = relative setback; Ptime = peak time (time from onset of pasting to peak viscosity); PT = pasting temperature (temperature at which peak viscosity was reached); RVU = Rapid Visco-Analyzer units

order for WBC among the three main samples under study was RF>CaS>GS likewise the formulated blends. The difference in the proportion of crystalline and amorphous regions within the granule resulted in these water absorption capacity variations (Kolawole et al., 2013). Thus, less amount of water is absorbed by starch granule with a smaller proportion of weakly bonded amorphous material (Kolawole et al., 2013) hence, GS showed such characteristic.

As reported by Oke et al. (2013), restricted type of swelling starches are desired for the production of noodles since the granule after swelling must remain intact and stable against shearing during thermal processing. The analyzed resulted presented in Table 2 revealed that, there was significant difference at $p<0.05$ among all the samples under study. CaS (27.27 g/g) recorded the highest whilst RF had the least (10.83 g/g). Also, GS had SP of 13.17 g/g. This difference was likewise depicted among their formulated blends with the exception of RF:GS (40:60) and RF:GS (80:20) which had no significant difference from each other. Also, the mean S of all the samples under study had significant differences among them, with GS (12.40%) recording the highest whilst RF (9.47%) recorded the least. The highest S recorded by the GS in this study is attributed to the easy solubility of the linear fraction (amylose) which leach out during swelling process since it is loosely linked with the rest of the macro molecular structure (Soni et al., 1993; Adebowale et al., 2014). The results obtained for SP and S were in the same range of the values reported by Qazi et al., 2014. However, Adebowale et al. (2014) recorded SP and S values for GS as 10.86 g/g and 10.17% respectively which are in contrast with the recorded results in this work which might be due to difference in varieties/cultivars and also the difference in temperature at which it was heated. As pointed out by Kolawole et al. (2013), the SP and S of ginger starch increases with an increased temperature.

Pasting characteristics of rice flour (RF), cassava (CaS) and ginger starch (GS) and their formulated blends

Table 3 highlights the pasting properties of RF, CaS, GS and their formulated blends. From the analytical results, there was significant difference ($p<0.05$) among the samples with all the pasting properties under study. The rank order for PV among the three main samples under study was CaS> RF>GS. There is an increase in viscosity with granule swelling along with amylose leaching, while a decrease of viscosity may be due to further shearing of granule (Sharma et al., 2009; Qazi et al., 2014). With the formulated blends, PV of RF increased as the CaS proportion increased this is confirmed by the results obtained by Qazi et al. (2014). However, the blends of GS showed otherwise that is, as the proportion of GS increased, only RF:GS (80:20) had a significant difference at $p<0.05$ p whilst RF:GS (60:40), (40:60) and (20:80) showed no significant difference from each other. GS recorded a higher TV than RF and CaS. The TV of RF increased with increasing GS and the opposite happened for CaS. The rank for RBD was recorded as CaS>RF>GS. The highest RBD value for the blends formulation was recorded by RF:CaS (20:80) and the least was recorded by RF:GS(20:80) which was as a results of the source of starch. FV and RSB recorded a similar ranking of RF>CaS>GS. The FV values of RF

Table 4. Textural properties of Rice flour paste (RF), cassava starch (CaS) and ginger (GS) starch and their formulated blends.

Sample	Hardness (g)	Adhesiveness	Springiness(mm)	Cohesiveness	Gumminess(g)	Chewiness(g×mm)
RF	101.25 ±7.14^{f}	-69.74±1.50^{g}	0.93±0.01^{b}	0.51 ±0.00^{e}	51.08±3.31^{d}	47.34 ±3.32^{f}
CaS	62.08±3.00^{g}	ND^{a}	1.83±1.22^{a}	0.85 ±0.04^{a}	53.00±5.00^{d}	55.83 ±4.76^{ef}
GS	460.48±9.22^{a}	-20.72^{b}±2.12^{b}	0.85±0.12^{b}	0.23 ±0.02^{h}	81.56±11.25^{a}	91.17 ±8.73^{a}
RF:CaS (80:20)	103.73±1.47^{f}	-31.91±3.99^{bc}	0.93±0.00^{b}	0.60±0.01^{d}	62.44 ± 0.55^{b}	58.10± 0.56^{de}
RF:CaS (60:40)	103.20±1.97^{f}	-10.18±1.32^{b}	0.96 ±0.01^{b}	0.68±0.01^{c}	70.63±0.58^{bc}	66.76± 0.77^{bcd}
RF:CaS (40:60)	90.61±3.03^{f}	ND^{a}	1.01±0.02^{b}	0.73± 0.02^{bc}	65.71 ±3.02^{c}	66.39± 3.86^{bcd}
RF:CaS (20:80)	63.62±2.16^{g}	ND^{a}	1.10±0.20^{b}	0.76 ±0.02^{b}	47.98±2.11^{d}	52.87 ±8.58^{ef}
RF:GS (80:20)	141.92±7.06^{e}	-16.74 ±1.50^{d}	0.94±0.03^{b}	0.46±0.05^{ef}	65.04 ±3.02^{c}	61.23±1.38^{cde}
RF:GS (60:40)	177.61±1.05^{d}	-23.41±5.67^{e}	0.95±0.00^{b}	0.42±0.06^{f}	75.79 ±7.16^{ab}	72.19 ±7.60^{b}
RF:GS (40:60)	238.81±13.15^{c}	-13.23 ±1.22^{cd}	0.85±0.03^{b}	0.32±0.04^{g}	77.15±6.43^{ab}	65.11 ±2.35^{bcd}
RF:GS (20:80)	293.34±21.90^{b}	-7.78±1.63^{b}	0.88±0.04^{b}	0.27±0.01^{h}	78.88 ±5.41^{ab}	69.05 ±2.46^{bc}

Means followed by different letters within the same column are significantly different from each other at P<0.05. Also, ND = not detected. HD = Hardness, AD = adhesiveness, SP = springiness, CO = cohesiveness, GU = gumminess, and CH = chewiness.

reduces as the proportion of CaS increases except that of RF:CaS (80:20) which deviated but falls in agreement with the results by Qazi et al. (2014) who recorded increasing values of FV as the CaS increased. However, though the RSB values for RF was decreased as the proportion of GS got increased, the values recorded were closer to the values recorded for that of RF than that of GS; Qazi et al. (2014) reported similar results. The results recorded in this study may be as a result of the granule size of the starches involved since granule size of the blends plays an important role in the setback (Punchaarnon et al., 2008). Both P_{time} and P_T also recorded a similar ranking of RF>GS>CaS. The difference in P_T among RF, GS and CaS might be as a result of the changes in the interior structure of starches which can occur in both amorphous and crystalline (Katayama et al., 2002; Thao and Noomhorm, 2012). The addition of CaS significantly reduced the pasting temperature of RF which indicates a reduction in the energy requirement during processing of various products with such blends and therefore, makes it better to be considered over GS when there is the need to save energy. When all other properties are equal, starch/flour with lower P_{time} and P_T may be desired more for technical and economic reasons (Iwuoha, 2004; Baah et al., 2009; Oke et al., 2013). However, for thermal, shear and mechanical stability, starches with high P_T will rather be considered since they have a strong bonding forces within the granule interior which provide higher resistance to mechanical agitation, hence, the results of lower PV and SW (Peroni et al., 2006). To determine the industrial application and use of flour/starch in various food products, pasting properties play an important role since they influence the texture, shearing and mechanical stability as well as the digestibility of starchy foods.

Textural properties of RVA gels

As summarized in Table 4, the textural properties of Rice flour (RF), Cassava starch (CaS), ginger (GS) starch and their formulated blends varied significantly. From the results obtained for hardness, GS recorded the highest hardness of (460.48 g) followed by RF (101.25 g) then CaS (62.08 g). The hardness value recorded for GS is related to the presence of strong bonding force within the granule interior as observed for its pasting properties and swelling power (Peroni et al., 2006). Harder gels exhibited by starches tend to have higher amylose content and longer amylopectin chains (Mua and Jackson (1997). Peroni et al. (2006) recorded a higher amylose content value of 26.5% for ginger starch (GS) and a lower amylose content of 19.8% for CaS hence, the high and low hardness as recorded for GS and CaS respectively in this study might be as a result of the variation in their amylose content. Results from Sandhu and Singh (2007), showed that amylose had a positive correlation with hardness (r=0.511, p<0.05) and gumminess (r=0.792, p<0.01) of starch gels. A highly significant correlation was found between high amylose and general acceptability of rice noodles (Bhattacharya et al., 1999). The addition of GS increased the hardness of the RF paste in accordance with the ratio whereas the increment of CaS rather reduced the hardness of RF and the values were more closer to the value obtained for CaS. The adhesiveness of RF and GS were (-69.74 g*s) and (-20.72 g*s) respectively whilst that of CaS, RF:CaS (40:60) and RF:CaS (20:80) were *not detected* this result is not different from the result obtained by Li et al. (2014) as they also did not record any values for adhesiveness of CaS. The adhesiveness recorded for the formulated blends of RF and GS at various ratios had a

Table 5. Storage modulus (G'), loss modulus (G") and tanδ of rice flour paste (RF), cassava starch (CaS) and ginger (GS) starch and their formulated blends at 10.0 Hz.

Sample	G' (Pa)	G"(Pa)	tan (δ)
RF	93.45±1.6^{a}	21.89±0.6^{c}	0.23±0.01^{h}
CaS	33.81±1.4^{e}	17.29±0.3^{ef}	0.51±0.02^{a}
GS	46.94±1.6^{d}	21.30±0.6^{c}	0.45±0.02^{b}
RF:CaS (80:20)	89.59 ±9.3^{a}	27.64±2.0^{a}	0.31±0.01^{e}
RF:CaS (60:40)	67.37±4.8^{c}	24.70±1.0^{b}	0.37±0.03^{d}
RF:CaS (40:60)	68.38±4.1^{c}	24.16±0.1^{b}	0.35±0.03^{d}
RF:CaS (20:80)	53.42±4.4^{d}	22.50±0.4^{c}	0.42±0.03^{c}
RF:GS (80:20)	80.32±7.0^{b}	20.76±1.0^{c}	0.26±0.01^{gh}
RF:GS (60:40)	65.66±3.6^{c}	17.60±0.4^{ef}	0.27±0.01^{fg}
RF:GS (40:60)	54.43±9.2^{d}	16.20±1.6^{f}	0.30±0.02^{ef}
RF:GS (20:80)	50.87±2.7^{d}	18.25±0.6^{d}	0.36±0.01^{d}

Means followed by different letters within the same column are significantly different from each other at P<0.05.

great influence on the adhesiveness of RF since the values recorded were closer to that of GS. In this study, springiness (SPR) is the only parameter which did not record any significant difference at p<0.05 among RF, CaS, GS and their blends. This brings us to the conclusion that the addition of either CaS or GS did not affect the springiness of RF. The cohesiveness ranking was recorded as CaS>RF>GS. The cohesiveness of RF increased with increasing CaS and the values were closer to that recorded for CaS. In contrast, the addition of GS rather reduced the cohesiveness as the proportion of GS increased. Whilst the gumminess of RF was greatly affected by the addition of CaS, the increasing addition of GS did not have a significant effect on RF. There was a significant difference at p<0.05 recorded in the rank RF<CaS<GS for chewiness parameter. The chewiness of RF was greatly affected by the addition of GS whilst the addition of CaS slightly affected the chewiness of RF. Based on the results obtained in this study, it can be concluded that CaS and GS had different textural properties. These variations in the textural properties significantly influenced the textural properties of RF when blended in various proportions and subsequently will affect the final product such as noodle's cooking quality and acceptance since the overall quality of cooked noodles is basically assessed by its texture.

Dynamic rheological properties of RF, CaS, GS and their formulated blends

Table 5 summarizes the G' and G" values at 10.0Hz of RF, the individual starches and the blends at 25°C. As shown by the dynamic moduli (G' and G") values, it was revealed that all the blends exhibited a weak gel behavior due to the positive nature of the slopes and the magnitude of G' (33.81-93.45 Pa) which were much higher than those of G" (16.20-27.64 Pa). From Figures 1 and 3, it can be seen that there is a significant change in the G' results of RF when blended with CaS and GS in the various ratios than the changes in G" respectively. The discrepancies in the granules properties such as rigidity and integrity results in the changes of in their elastic properties (Lu et al., 2008). This phenomenon shows that the elasticity of RF is greatly affected by the addition of these starches at various ratios; similar results were recorded by Sun and Yoo (2011) as they blended rice flour with potato starch. The G' values of RF:CaS (93.45-53.42 Pa) at various ratios were significantly lower than that of RF however, the G"(21.89-27.64 Pa) value of RF saw a slight increase. Also, the dynamic moduli of RF (G'=93.45-50.87 Pa, G"=21.89-16.20 Pa) was constantly reduced by the addition of GS at an increasing ratios (Figure 3). This observed result indicates that these blend samples could have been diluted by individual starches with lower dynamic moduli compared to RF.

All the samples under study were more elastic than viscous since the tan δ (G"/G') values were within the range of 0.23-0.51 (tan<1). The tan δ values of RF blends (0.26-0.42) were much lower than that of the individual starches GS and CaS (0.45 and 0.51 respectively) (Figures 2 and 4). The higher tan δ values recorded by the individual starches in effect raised the tan δ values in their blends with RF thereby reducing the elasticity of RF. However, the tan δ values recorded for RF:GS were smaller (0.26-0.36) as compared to that of RF:CaS (0.31-0.42) blends. In conclusion, even though none of the starches under study could increase the elasticity of RF

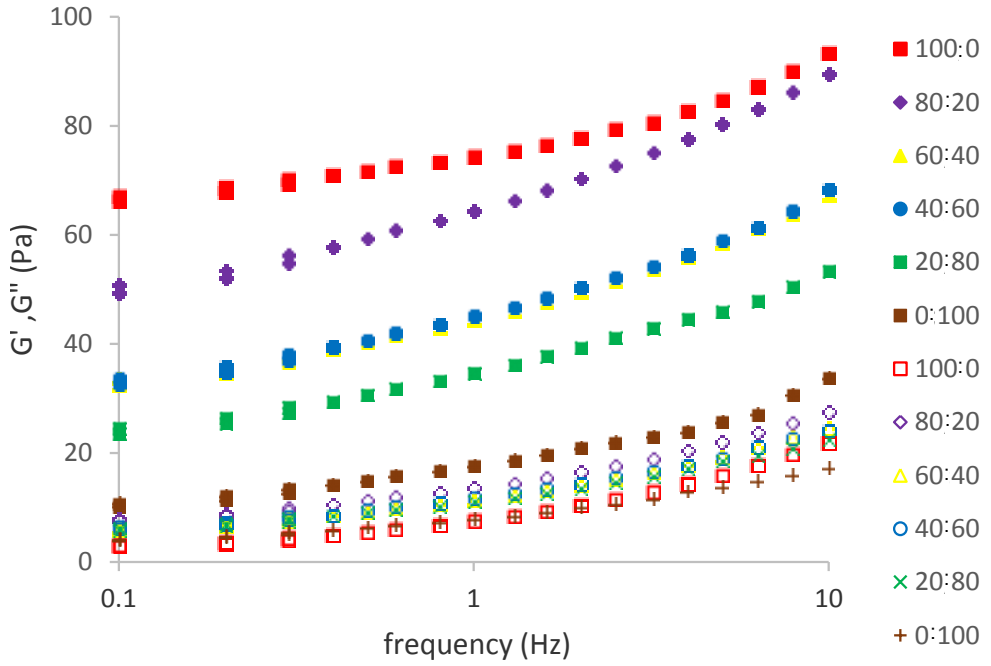

Figure 1. Dynamic mechanical spectra as a function of frequency for RF: CaS blends at 25°C (Closed symbols represent G', open symbols represents G").

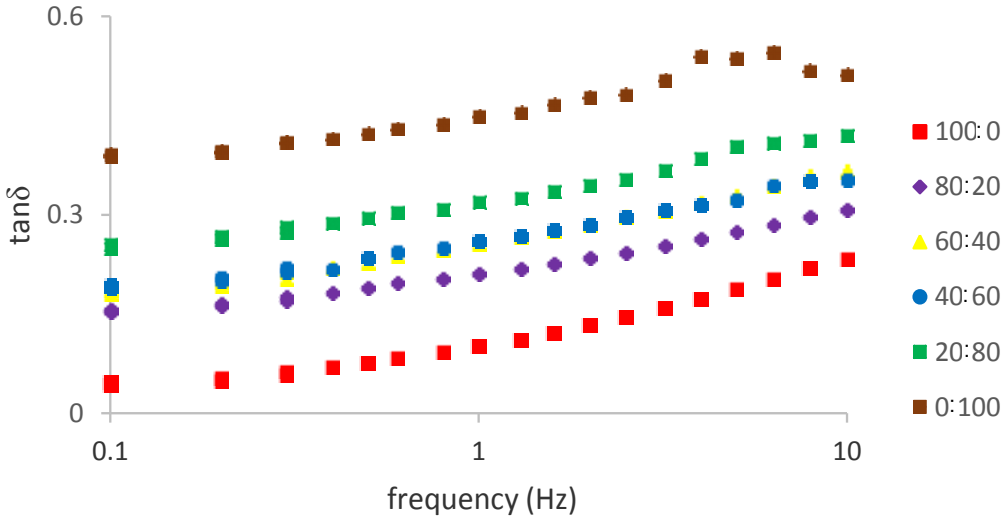

Figure 2. The tan δ as function of frequency for RF: CaS blends at 25°C.

however blends with GS did not have much reduction effect on the elasticity of RF and therefore can be considered over Cas. These softer and weaker gels observed for both CaS, GS and their formulated blends might be as a result of the reduction in leached-out amylose, resulting in a reduction of molecular entanglements for the gel network (Oh et al., 2010).

CONCLUSION AND RECOMMENDATION

In this study, a broad variation of pasting, textural and dynamic rheological properties were observed among RF, CaS, GS and their formulated blends. Under the pasting property, GS exhibited the appropriate characteristics in most of the pasting parameters over

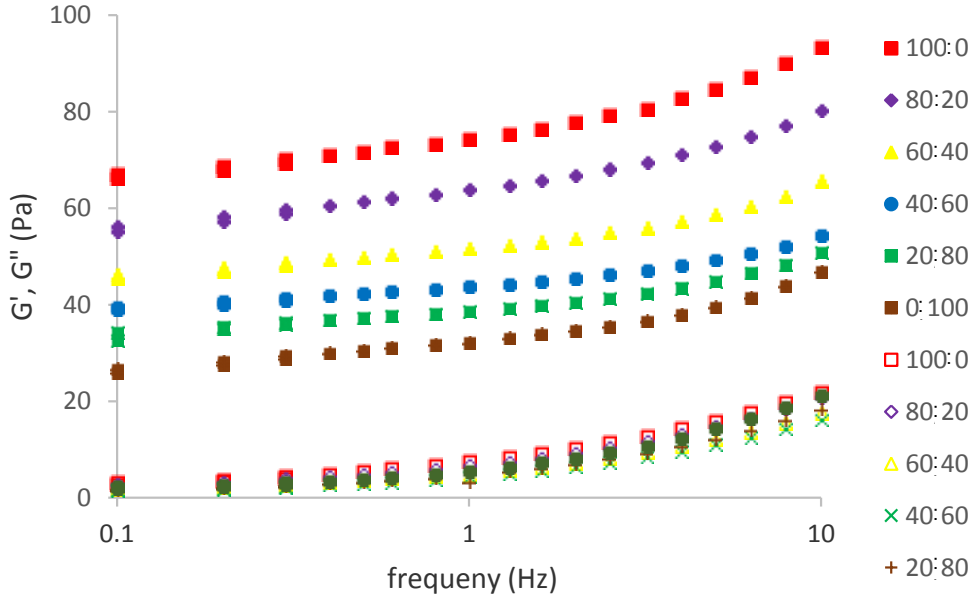

Figure 3. Dynamic mechanical spectra as a function of frequency for RF: GS blends at 25°C (Closed symbols represent G', open symbols represents G").

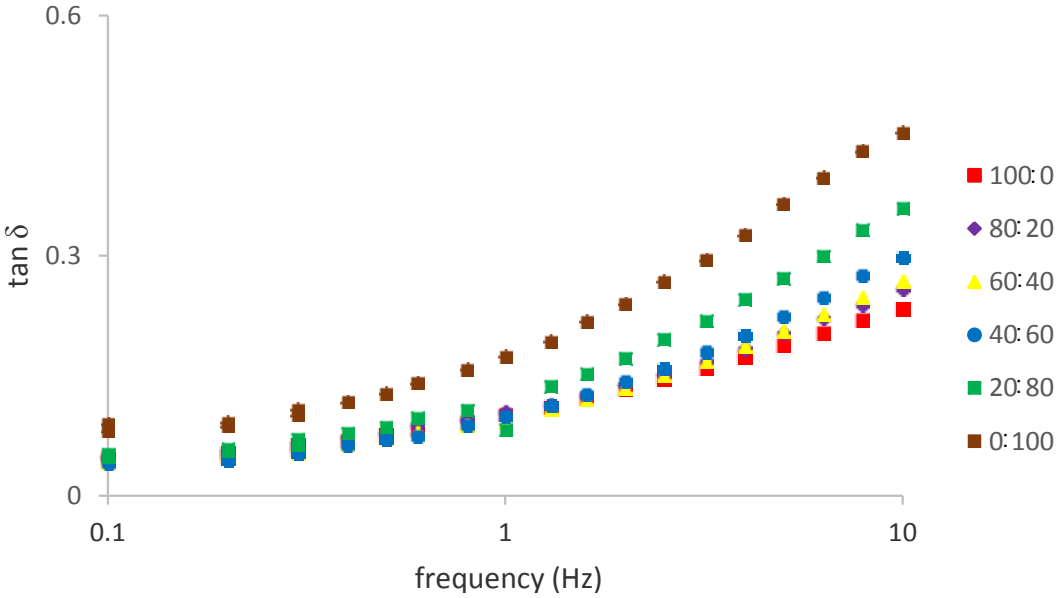

Figure 4. The tanδ as function of frequency for RF: GS blends at 25°C.

CaS such as, GS recorded a higher TV, FV, P_t as well as a slightly lower (PV and RBD) and slightly higher P_T. That is, GS having a higher FV will result in firmness of noodles produced (out) thereby increasing the firmness of RF noodles when blended. Starches with higher TV generally exhibited superior eating quality and lower cooking loss whilst those with higher FV are related to high shear resistance hence, GS exhibiting these characteristics makes it better to be selected over CaS in the blend formulations with RF. However, CaS recording a lower and higher values for P_T and PV respectively makes it better to be considered for reduction in energy requirement during processing. More so, textural properties are major characteristics for assessing the

quality of rice noodle. GS recording the higher value of HD which eventually resulted in higher HD in all its blend with RF, makes it better to be selected over CaS. Finally, CaS and GS and their blends with RF all exhibited a weak gel behavior as shown by their dynamic moduli (G' and G") values. Even though, none of these starches under study could increase the elasticity of RF however blends with GS did not have much reduction effect on the elasticity of RF and therefore can be considered over CaS. The results obtained in this study, makes GS fit to be considered in the modification of RF for noodle production. Upon the various characteristics exhibited by native GS in this study, it is recommended that various modification methods be used to improve the properties of GS which will help widen its application scope in the food industry.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Effects of blanching time and dehydration condition on moisture and ascorbic acid retention in tender pumpkin *(Cucurbita moschata)* leaves

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A study was conducted to assess retention of moisture and ascorbic acid in tender pumpkin (*Cucurbita moschata*) leaves subjected to different blanching times and dehydration conditions. Equal portions of the leaves were blanched at 5, 10 and 15 min. A half of each portion was dehydrated under a shade and the other under direct sunlight. All the samples were then analysed for moisture and ascorbic acid contents in comparison with those of the raw-leaf sample. The fresh samples (wet basis) had 79.26±5.08 mg/100 g ascobic acid compared to the processed samples, which ranged from 41.10±2.94 to 73.39±5.87 mg/100 g in the blanched shade-dehydrated sample and 17.61±0.00 to 35.23±5.08 in the sun-dehydrated blanched sample. The results further showed that the samples that were blanched for a shorter time and dehydrated under a shade retained a significantly higher ($p<0.05$) amount of ascorbic acid compared to those that were blanched longer and dehydrated under direct sunlight. There was no significant difference in moisture content between the shade-dehydrated and sun-dehydrated samples, which were found to be in the ranges of 13.22±0.09 to 14.23±0.27% and 12.45±0.035 to 13.42±0.52%, respectively. It was, therefore, concluded that shorter blanching time and shade-dehydration can retain ascorbic acid in tender *C. moschata* leaves without compromising moisture content of the product.

Key words: *Cucurbita moschata*, sun-dehydration, shade-dehydration, ascorbic acid, pumpkin leaves.

INTRODUCTION

Pumpkin plant (*Cucurbita moschata*), also known as 'tropical pumpkin', is one of the well-known and highly utilised plants cultivated throughout the world, particularly in lowland areas of Asia, Africa and America. Pumpkin plant is unique in a way that almost every part of it (except the roots) is edible. Flowers, fruit, and long tendril

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shoots and leaves are relished as vegetable. The leaves and tender young shoots are cooked as vegetables and used as potherb or added to soups and stews (Lim, 2012a). Pumpkin blossoms are edible raw or cooked but when mature, the fruit is cooked as a main course or side dish, and used as an ingredient, in pies, soups, stews, and bakery preparations (Lim, 2012a; Durante et al., 2014). Seeds are eaten raw, dried or roasted and can be served as a snack but can also be ground into a powder and used with cereals and in bread making (Lim, 2012a).

This has made pumpkin a plant of interest for researchers. Although a lot of studies have been conducted on the pumpkin plant, most of them, however, have targeted the fruit and seeds only (Stevenson et al., 2007; Mala et al., 2016). Pumpkin leaf is one of the most consumed parts of the plant in some parts of the world, including the Sub-Saharan Africa (Lymo et al., 1991; Lim, 2012a), but limited information on the same is available.

Vegetables play crucial roles in alleviating hunger and food security by contributing bulk of the nutritional components in the diets of people where animal products are scarce (Mepba et al., 2007). Just like many other green leafy vegetables, pumpkin leaf is tasty and nutritious and is popular in countries such as Kenya, Malawi, Zambia, Zimbabwe, among others. The leaves are a valuable source of nutrients (which are usually in short supply in daily diets) especially in rural areas (Lymo et al., 1991; Mepba et al., 2007) where they contribute substantially to minerals, fiber, protein and vitamins, especially β–carotene and ascorbic acid (FAO,1988; Mwaniki et al., 1999; Adegunwa et al., 2011; Kakade and Neeha, 2014). Pharmacologically, leaves in the family of Cucurbitaceae are believed to have a number of health benefits. In ethno medicine users, it has been reported that the leaves are used for reduction of fever, treatment of nausea and boosting haemoglobin content. It is also believed that the leaves help in the prevention of convulsion, in which young leaves are sliced and mixed with coconut water and salt, then stored and used for the treatment. Moreover, the leaves have been reported to have the ability of boosting fertility as a result of zinc and essential fatty acids present, protect the liver and cure anaemia (due to the presence of iron). Furthermore, the sufficient amount of vitamin is reported to help in boosting of vision as well as supplementing effect on the daily protein requirement of the body (Dhiman et al., 2012; Lim, 2012a, b). A study by Kwak and Ju (2013), *in-vitro*, has shown the anti-cancer propertied of extracts from *C. moschata* leaves.

In most cases, pumpkin plant is mainly grown for the fruit, as such, availability of the leaf as vegetable depends on the time of the year when the fruit is considered to do well. Although pumpkins are not necessarily seasonal in nature, in countries like Malawi, they are mostly grown during the rainy season; as a result, the leaves are in abundance during this period and become scarce thereafter. To ensure their constant availability, in most developing countries, pumpkin leaves are traditionally processed into their dehydrated form, which mostly involves blanching and sun-dehydration (Lymo et al., 1991; Mepba et al., 2007). Although this is done traditionally, the scientific reasoning is that the blanching deactivates enzymes, while dehydration reduces water activity, which prevents growth of moulds and other microorganisms; thereby preventing spoilage of the preserved vegetable (Fellow, 2009).

In fact, there are several methods of processing vegetables for preservation, which include sun-dehydration, canning, vacuum packing, minimal processing, refrigeration, freezing and irradiation (Fellow, 2009). Of all these processing methods, sun-dehydration has been regarded as the most effective, cheap and popular method of processing pumpkin leaves for preservation by the local people in Malawi compared to the other methods. Under this method, people prefer blanching then sun-dehydration compared to the one which only involves sun-dehydration without blanching with the same reasoning that blanching will help to deactivate spoilage enzymes and kill spoilage microorganisms hence help the vegetable to be of higher quality. While fresh pumpkin leaves are perishable due to high water activity, dehydrated pumpkin leaves stay longer as compared to the fresh ones. Dehydrated vegetables stored in good containers and kept in dry conditions can have a shelf life of more than a year (Musarirambi et al., 2010). Dehydration also reduces weight of the vegetable thereby making it easy for transportation (Fellow, 2009).

Although this kind of processing has been regarded as significant in preserving pumpkin leaves, the steps of blanching and sun-dehydration have great potential of reducing some nutrients in the vegetable, more especially, ascorbic acid (vitamin C), which is soluble in water and prone to oxidation upon exposure to light (Lawal et al., 2015; Okpalamma et al., 2013; Adegunwa et al., 2011). Despite the fact that, there is a possibility that the blanching and dehydration can lead to ascorbic acid loss, there is no clear information on the amount that is lost as a result of this processing method. Lack of knowledge on the retained amount might interfere with the formulation of balanced diets hence a need for a study of this nature that focuses on the effect of cooking time and/or dehydration condition on ascorbic acid loss and suggest how best the vegetable can be processed to ensure its possible maximum retention.

MATERIALS AND METHODS

Sample collection

Fresh and tender pumpkin leaves of the *C. moschata* species (over 2 kg) were purchased in morning hours (around 8:00 am) from a

Table 1. Moisture and ascorbic acid retentions in differently processed dehydrated pumpkin (*Cucurbita moschata*) leaves.

Sample name*	Moisture content (%)	Moisture retention (%)	AA Conc. (mg/100 g)	AA retention (%)	AA loss (%)
Fresh leaves	78.87 ± 3.67^{a}	-	79.26 ± 5.08^{a}	-	-
5 min SHD	14.23 ± 0.27^{b}	18.04	73.39 ± 5.87^{a}	92.60	7.40
10 min SHD	13.33 ± 0.21^{b}	16.90	46.97 ± 2.94^{b}	59.26	40.74
15 min SHD	13.22 ± 0.09^{b}	16.76	41.10 ± 2.94^{bc}	51.85	48.15
5 min SD	12.45± 0.35^{b}	15.79	35.23 ± 5.08^{c}	44.44	55.56
10 min SD	12.83 ± 0.17^{b}	16.27	29.35 ± 2.94^{d}	37.04	62.96
15 min SD	13.42 ± 0.52^{b}	17.01	17.61 ± 0.00^{e}	22.22	77.78

*Sample name represents method of preparation: The first part stands for blanching time in minutes and the last upper case letters represents dehydration condition (SHD = shade dehydrated, SD = sun-dehydrated). Different superscript letters indicate significant difference among mean values of triplicate tests $p<0.05$.

single seller at a local market. The leaves were immediately brought in airtight plastic carrier bags to a laboratory, which was about 3 km from the market, for processing. Thus the vegetables arrived the laboratory still very fresh. While analysing initial contents of ascorbic acid and moisture in the fresh unprocessed portion of the sample, the rest of the vegetables were stored in the same carrier bag in a refrigerator and were processed within 4 h. This was done to minimise action of spoilage microorganisms and enzymes that could alter characteristics of the vegetables. All chemicals used were of analytical grade.

Sample preparation

The pumpkin leaves were first cut into slices of about 1 cm in width using a stainless steel knife then divided into 4 portions of 400 g each. One portion was analysed immediately for moisture and ascorbic acid contents. The remaining 3 portions were immersed into separate beakers of 500 mL pre-boiling distilled water and boiled further for 5, 10 and 15 min, respectively. At the end of the boiling time, each sample was drained in a polypropylene colander until the liquid stopped dripping. Each sample was then divided further into two equal portions. Each portion of these blanched samples was spread on a separate clean traditional bamboo winnower and one portion dehydrated under shade at ambient temperature of about 22 to 26°C, while the other one under direct sunlight (32±4°C). The dehydration process was observed for 5 days and the leaves were removed and put into air-tight polythene bags and kept at dry, well ventilated place, ambient temperature (22 to 26°C) until analysis. The samples were named according to the blanching time and method of dehydrations for example; '5 min SD' was a sample which was blanched for 5 min and sun-dehydrated, while the '5 min SHD' represents one that was blanched for the same 5 min but was shade-dehydrated.

Moisture retention determination

Moisture content was determined using the AOAC (2000) method. Crushed sample (2 g) was put into beaker, which was previously cleaned, dehydrated for 1 h in an oven and cooled in a desiccator for 30 min. The initial weight of the beaker with sample was recorded. The sample in the beaker was then dehydrated for 6 h in an air circulating oven set at 100°C, cooled in a desiccator for 1 h, then reweighed. Moisture content was calculated as a percentage using the following formula:

$$\text{Moisture content (\%)} = (A - B) / C \times 100$$

Where: A = initial weight of beaker with sample; B = final weight of the beaker plus sample after oven-drying; C = initial weight of the sample before oven-drying.

Moisture retention was calculated as a percentage of the dehydrated sample moisture content to that of original fresh leaves.

Ascorbic acid retention determination

Ascorbic acid (AA) was analysed by AOAC (2000) titrimetric method using 2,6-dichlorophenolindophenol (DCPIP) as a redox dye. To begin with, 30 g of dehydrated sample was ground finely using a motor and pestle to pass through a 100 mesh sieve. Then, 90 mL of water was added to make a ratio of 1:3, and the mixture transferred into a 200 mL beaker. Two spatulas of activated charcoal were added and the mixture was boiled for 10 min to remove the green colour that would interfere with the observation of colour change during titration. After cooling in a water bath, the sample was filtered through a Whatman No. 1 filter paper. The filtrate, in triplicate, was then used for the analysis of ascorbic acid content in the sample using the above AOAC standard method. Ascorbic acid retention was calculated as a percentage of dehydrated sample ascorbic acid content to that of original fresh leaves.

Statistical analyses

One way analysis of variance (ANOVA), with Duncan's multiple range test, using a SAS program (version 8.1, SAS Institute Inc., Cary, NC, USA) was conducted to assess significance of differences ($p<0.05$) among the obtained mean values.

RESULTS AND DISCUSSION

The results for both moisture content and ascorbic acid determinations and retentions of the differently processed dehydrated pumpkin leaf samples are presented in Table 1.

Moisture retention

In the preservation of vegetables by dehydration technique, moisture content of the final product is of great importance as it determines its longevity on the shelf.

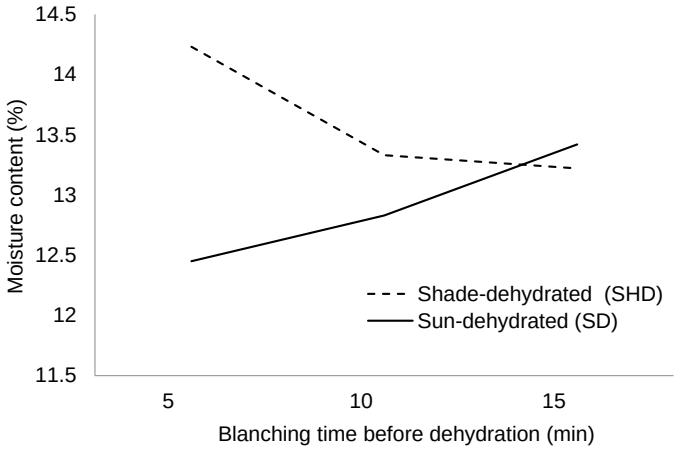

Figure 1. Trends in the retention of moisture by pumpkin (*C. moschata*) leaves blanched for varied times and dehydrated under direct sunlight and shade.

Usually, dehydration under direct sunlight is preferred as it is believed to reduce the moisture to the minimum level. However, from Table 1, it can be observed that there were no significant differences ($p>0.05$) among samples dehydrated under direct sunlight and those dehydrated under a shade. Much as the direct sunlight might be efficient in terms of the dehydration time, it has great potential to affect retention of some nutrients such as vitamin C and being a free provision, the sun's efficiency has no any economic value. As such, dehydration techniques that can retain nutrients would be of great importance. Compared to the findings of similar studies, the moisture contents in the fresh and processed dehydrated leaves were substantially lower than those reported by Onoja (2014) in fluted pumpkin (*Telfairia occidentalis*) leaves. This difference in the moisture content of the fresh leaves may be attributed to differences in plant species and water composition of the area where the plants for these two studies were grown, while those of dehydrated leaves may be due to the length of dehydration time, ambient temperature and air circulation of the dehydration environment.

A thorough scrutiny of the results in this study further revealed that samples dehydrated under the direct sunlight retained less moisture compared to the shade dehydrated ones, but the contents increased as blanching time increased. Thus, the sample, which was blanched for 15 min retained more moisture followed by the ones blanched for 10 then 5 min, in that order. This scenario may not necessarily reflect that the blanching process led to absorption of more water by the sample. This is so because, observation has shown that as leafy vegetables get boiled, they tend to shrink and liquid gets released from them resulting in an increase in the amount of liquid in the boiling vessel. However, there is a possibility that as the liquid got released from the leaf, external cells of the leaf got compacted together to form a semi-permeable membrane that prevented some water from getting out of the leaf. The exposure to the direct sun radiation possibly assisted in the faster formation of this membrane compared to shade-dehydration, where the scenario was different. The shade-dehydrated samples had their moisture retention decreasing with increasing blanching time. These different trends are clearly presented in Figure 1. No study, however, was found to compare these findings with.

Ascorbic acid retention

The results of the ascorbic acid retention in the processed pumpkin leaves are also presented in Table 1. There was a significant difference ($p<0.05$) between the fresh and processed samples, except the 5 min SHD, with the fresh samples having the highest amount. Among the processed samples, all of them differed significantly ($p<0.05$) in the order of 5 min SHD > 10 min SHD > 15 min SHD > 5 min SD > 10 min SD > 15 min SD. This showed that the samples, which were dehydrated under a shade, had generally higher values than the sun-dehydrated ones. At the same time, ascorbic acid kept reducing as blanching time increased. The ascorbic acid in the 5 min shade-dehydrated sample did not differ significantly with the fresh one. However, with the scope of this study, it was not certain as to whether the 5 min of blanching were enough to achieve green colour retention, deactivation of microorganisms and enzymes, and improvement of flavour, which are the main reasons for blanching vegetables (Kakade and Neeha, 2014; Ahmed et al., 2001). The study conducted

by Vyankatrao (2014) in mint, coriander, curry leaves and bitter gourd revealed that highest retention of ascorbic acid alternated between sun-dehydrated and shade-dehydrated among different vegetables, indicating that the findings of this study were specific to leaves of *C. moschata* and cannot be easily generalised to all leaves that would be dehydrated under the same conditions. Type of the leaf is also an important factor. However, a number of studies in drumstick (Molinga) leaves (Joshi and Mehta, 2010) are in concord with the findings of this study.

Conclusion

The findings of this study have shown that in the preservation of *C. moschata* leaf vegetables by dehydration method, duration of branching and light intensity during dehydration have an effect on the retention of vitamin C. Reduced blanching duration accompanied by shade dehydration can retain more of the vitamin. Proper shade dehydration of the vegetable cannot compromise the shelf-life of the vegetable as the retained moisture may not be different from that of the vegetables dehydrated under direct sunlight.

CONFLICTS OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Multi-response optimization of the energy value and rheological parameters in the formulation of a complementary infant-gruel flour

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The objective of this study is to present the formulation of complementary infant-gruel flour by applying the multi-response optimization with responses centered on physico-chemical properties, energy value and rheological parameters. A Scheffé simplex network-derived mixture design was adopted to determine the optimal proportions of malted sorghum, malted sesame and dried banana flours, which were the factors considered in the design. The different flour mixtures obtained from the design were cooked in water, using flour to water ratio of 3:7 (w/v) to obtain gruels, and the responses were analysed based on specifications for complementary foods for babies around 6 months old. The results revealed a zone of compromise whose optimal points corresponded to minimum-maximum specifications of 39 to 44% for malted sorghum, 26 to 36% for malted sesame and 20 to 35% for dried banana. The standard protocol for gruel flour production obtained can be used for local production of gruel flours.

Key words: Infant flour specifications, banana, sesame, sorghum, malting, mixture design.

INTRODUCTION

Maternal milk is the complete ideal food used for the feeding of infants from birth to the age of four months (Eidelman and Schanler, 2012). Above this age, the nutritional needs increase and maternal milk alone becomes insufficient (CODEX, 2006) requiring the use of complementary foods. During the transition period from exclusive maternal milk to adult foods, mothers have the choice of producing gruel (also called purée or porridge depending on the consistency) by themselves or using imported flours for gruel production (de Pee and Bloem, 2009). However, traditional gruels are less nutritional as their protein content and energy value remain lower than

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the limits fixed by the WHO: 0.055 g/g and 1 kcal/g, respectively (Onoja et al., 2014; Ndagire et al., 2015).

Even though imported flours present better nutritional properties, they are relatively expensive for most African households; meanwhile their production using local food products is possible (Adeniyi, 2012). In the commercial platform, they exist in two forms: Instant infant flours, easy to prepare by diluting in hot water and non-instant infant flours destined for cooking before consumption. Compared to instant infant flours, the production of non-instant infant flours is less complex and less expensive (Adeniyi, 2012; Obiakor-Okeke et al., 2014; Ikujenlola et al., 2017).

For non-instant infant flour production, a precise content of carbohydrates, lipids, proteins, mineral salts and vitamins is recommended to ensure the right nutritional complementation of maternal milk (CODEX, 2006). These basic nutritional components can be obtained from various food products depending on the geographical location. Cereals like sorghum, millet, corn and rice, are important sources of carbohydrates in infant flours (Anigo et al., 2010; Adeniyi, 2012; Obiakor-Okeke et al., 2014; Bolarinwa et al., 2016). Proteins are provided by powdered milk, black-eyed pea, soya beans and dry beans (Soro et al., 2013; Onoja et al., 2014; Ikujenlola, 2014; Ndagire et al., 2015). For the lipid needs, oily grains such as groundnuts, pumpkin seeds, sesame or vegetable oils are used (Onabanjo et al., 2009; Adeniyi, 2012; Ijarotimi and Keshinro, 2013). Concerning the mineral and vitamin needs common fruits or supplementary minerals and vitamins (de Pee and Bloem, 2009) are used.

Amongst the available cereals in Cameroon, sorghum and millet, whose production tonnage reached 1,187,531 tons in 2010 (MINADER, 2012) and 1,150,000 tons for sorghum after four years (FAOSTAT, 2014), are currently used traditionally in the production of infant flours. Sorghum is therefore a potential cereal in the preparation of infant flours, but it still needs some supplements in nutrients other than carbohydrates, which could be obtained from other sources. The lipid and protein fractions could be obtained from sesame (Elleuch et al., 2007), which is readily available (MINADER, 2012) and less allergic (Arjon et al., 2007) compared to other lipid sources. The choice of sesame is supported by the increase in its cultivated area in Cameroon, more than 21.4% in 2010 (MINADER, 2012) leading to a national production of 48,000 tons (FAOSTAT, 2014). Ripe bananas, well appreciated by weaning-age infants (Honfo et al., 2011) could be used to supplement for the vitamin and mineral contents (Abbas et al., 2009). Cameroon occupies the thirty-second position in the world's banana production with a tonnage production of 1,719,009 tons (FAOSTAT, 2014). Despite this wide variety of nutritional resources for the production of infant flour, there is little information regarding their use for infant flour production that respects the norms.

Concerning studies on flour-based products, several reports have been presented in the literature. Matalanis et al. (2009) studied the textural and thermal properties of sorghum starch pastes; Onyango et al. (2011) evaluated the effect of cassava starch on the rheological and crumb properties of sorghum-based batter and bread, respectively. Other authors studied the rheological behavior of banana purée (Ahmed and Ramaswamy, 2007; Alvarez et al., 2008; Maka Taga and Jiokap Nono, 2017), suspensions made of banana and wheat flours (Mohamed et al., 2010), semi-solid sesame paste (Abu-Jdayil et al., 2002; Çiftçi et al., 2008), sesame-based products (Alpaslan and Hayta, 2002; Razavi et al., 2007) and oil-in-water emulsions prepared with oil and protein isolates from sesame (Brewer et al., 2016). In addition, a recent study evaluated the effects of concentration and temperature on the rheological properties of sorghum, sesame and banana gruels (Maka Taga and Jiokap Nono, 2017). However, the aforementioned studies were geared towards investigating the rheological and textural properties of flour-based products formulated from ingredients other than a combination of sorghum, sesame and banana. The results presented are hence inadequate to accurately predict the rheological, nutritional and energy properties during the formulation of gruel flour using mixture design applied on sorghum, sesame and banana as input variables. The objective of this study is to formulate new complementary infant gruel flours, by combining malted sorghum, malted sesame and dried banana flours and to assess their nutritional, rheological and energy properties.

MATERIALS AND METHODS

Food products for gruel flour production

The food products used for gruel flour production were sorghum (*S. bicolor* cv. Safrari), white sesame (*S. indicum*) and ripe banana (*Musa acuminata*, Cavendish). Sorghum and sesame were obtained from the Institute of Agricultural Research for Development (IRAD) at Maroua (Far-North Region, Cameroon) while banana was obtained from a local market in Ngaoundere (Adamawa Region, Cameroon). The bananas were ripened to reach a colour index ranging from (6-7) based on the commercial peel colour scale (Aurore et al., 2009).

Physicochemical analyses

The water content was determined by AOAC (1990) method, the ash content by AFNOR (1981) method and the total nitrogen after mineralization of the samples according to Kjeldahl method (AFNOR, 1984). The colorimetric technic of Devani et al. (1989) was used for the nitrogen chemical dosing and the protein content was determined using the conventional conversion coefficient of 6.25 (AOAC, 1975).

The determination of reducing sugars was done by the DNS (3,5 Dinitrosalicylic acid) colorimetric method of Fischer and Stein (1961) and the total available sugars were determined in the same way after hydrolysis of the sugars by hydrogen sulfate(H_2SO_4, 1.5 N). The lipid content was determined after hexane soxhlet

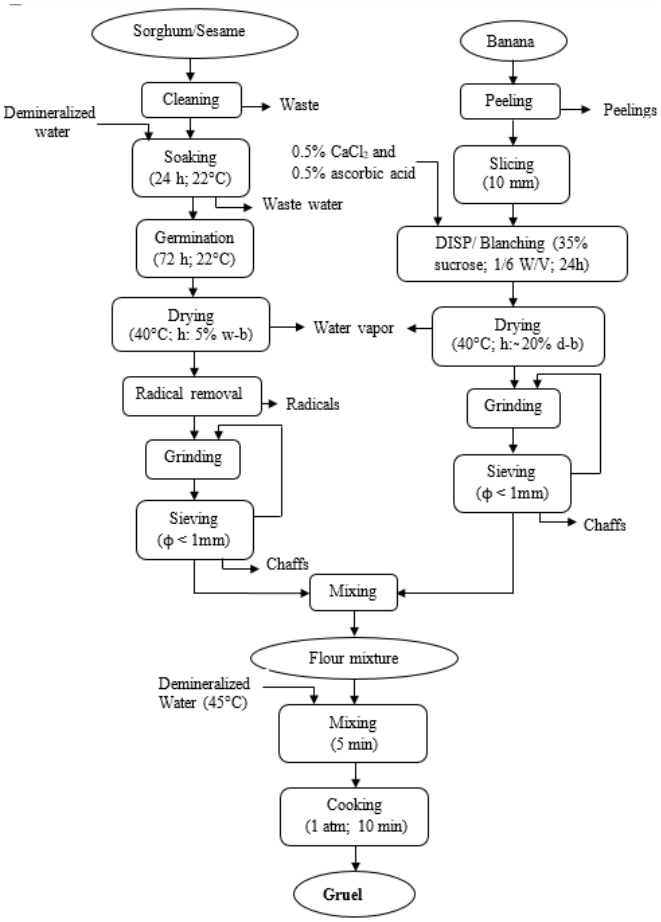

Figure 1. Process diagram for the production of a gruel using sorghum, sesame and banana. DISP: Dewatering-Impregnation-Soaking Process.

extraction as described by Boureley (1982).

Dynamics of germination rate and determination of the germination time

The rate of germination (*Gr*) was determined through a germination test using 100 good grains initially soaked in distilled water. The soaked grains were then spread on a wet filter paper, put in a petri dish maintained at 22±1°C and the filter paper was watered every 12 h. The germinated grains were counted each day until stabilization, which corresponded to the time of germination. Equation 1 was used to determine the germination rate, where N_g and N_0 are respectively the number of germinated grains at a given time and the number of initial good grains. The time required for germinating each cereal was determined and used during the gruel flour production (Maka Taga and Jiokap Nono, 2017).

$$Gr = (N_g/N_0).100 \quad (1)$$

Process for flour mixture and gruel production

The sorghum and sesame were separately treated as described by Elkhalifa and Bernhardt (2010) and Tizazu et al. (2010). Sorted, winnowed, and washed twice with distilled water. The cleaned grains were soaked in distilled water for 24 h at 22 ± 1°C with the soaking water renewed at the twelfth hour. After soaking, the seeds were then drained using a sieve, spread on a wet tissue that was made to imbibe water every 24 h, and allowed to germinate in the dark at 22 ± 1°C over a period. The germinated seeds were dried at 40 ± 1°C for 48 h. After cutting-off and discarding their cyanide-containing radicles (Traoré et al., 2003), the dried seeds were ground and sieved to obtain flour of particle-size less than 1 mm. The bananas were peeled, cut into slices of about 5.0 ± 0.5 mm thickness and subjected to a combined dewatering-impregnation-soaking process/blanching as described by Jiokap Nono et al. (2002). They were then dried (40 ± 1°C for 72 h) to reduce water activity, limit protein denaturation/browning reactions and then ground to small particle sizes (< 1 mm). The flours were mixed for 5 min with water at 45°C (using a flour to water ratio of 3:7 w/v) and the mixture (1 L) was placed in a stainless-steel pot (2 L capacity) and cooked with gentle heat using a two-burner gas stove for 10 min at atmospheric pressure, after reaching 95°C. The mixture was slowly stirred during cooking using a stainless-steel spoon. As mentioned by Trèche and Mouquet (2008), this procedure leads to the production of low viscosity purées and as such, most appropriate for infants. The overall process that was used for the preparation of the gruel flour mixture using the different ingredient is presented in Figure 1.

Table 1. Recommended specifications for complementary foods (from 4 months to 3 years old).

Reference	Units	Component	Minimum	Maximum	Comment
*	g/100 g of gruel	Carbohydrates	7.5	20	
		Lipids	3.1	5.4	
		Proteins	3.6	6.6	
	g/100 g db	Carbohydrates	25	70	
		Lipids	10	18	
		Proteins	12	22	
	Kcal/ 100 g gruel	Energy value	80	/	
	Kcal /100 g db	Energy value	400	/	
**	cP	Viscosity	/	1000	Around 6 months
	cP	Viscosity	/	2000	Around 8 months
Present work	(-)	Flow behaviour index	/	/	Maximize
	$Pa.s^{-n}$	Consistency index	/	/	Minimize

*: CODEX (2006) and Mouquet et al. (1998). **: Gerbouin-Rerolle (1996).

Table 2. Presentation of the different factor levels.

Factors	Lower level	Center	Upper level
Germinated sorghum (SOG, X_1)	0	0.5	1
Germinated sesame (SEG, X_2)	0	0.5	1
Dried banana (BS, X_3)	0	0.5	1

Determination of the energy value

The energy value was calculated by the EEC (1990) conversion method, based on the fact that 1 g of carbohydrate provides 4 kcal, 1 g of lipid provides 9 kcal and 1 g of protein provides 4 kcal. Therefore, the energy value (Ve) was calculated as follows (Equation 2):

$$Ve = 4X+9Y+4Z \quad (2)$$

Where X, Y and Z are respectively the dry matter percentages of carbohydrates, lipids and proteins.

Rheological measurements

Rheological analyses were conducted using a Brookfield DV-III Ultra rheometer (model HBDV-III Ultra, 8534447, Brookfield Engineering Lab., Massachusetts, USA). The disk-shaped spindle HA/HB-2 of 133 mm height; 47.12 mm diameter and 1.65 mm thickness was used. The apparent viscosity was calculated as described by Anonymous (1998) with a dimensionless factor of the spindle equal to 3200/N, where N (rpm) is the rotation speed. For the disk-shaped spindle N 2, the shear rate $\dot{\gamma}$ (s^{-1}) was determined as presented in Equation 3 (Mitschka, 1982):

$$\dot{\gamma} = (0.119 \cdot Tw)/\mu \quad (3)$$

Where T_w(%) and μ (Pa.s) are respectively the torsion torque and the apparent viscosity for each value of the rotation speed.

The rheological parameters (consistency index 'k' and flow behaviour index 'n') were determined by adjustment, either using the Herschel-Bulkley model (Equation 4) or using the power law model (Equation 5):

$$\tau = k \cdot (\dot{\gamma})^n + \tau_c \quad (4)$$

$$\tau = k \cdot (\dot{\gamma})^n \quad (5)$$

The model with a better coefficient of determination and P-values less than 0.05 was chosen.

Mixture design and response surface methodology

The mixture design method was used to determine the optimal mixing proportions of the three different ingredients (sorghum, sesame and banana flours) used in the production of a gruel flour mixture respecting the nutritional, rheological and energy specifications presented in Table 1. In the mixture design, the factors were the proportion of each ingredient involved in the gruel flour mixture, that is: The proportions of malted sorghum (SOG, X_1), malted sesame (SEG, X_2) and dried banana (BS, X_3). The values of the factors (X_i) were thus comprised between 0 and 1 ($0 \leq X_i \leq 1$) as shown in Table 2. Based on the specifications for infant flours presented in Table 1, the responses were the soluble sugar content (Y_1), total sugar content (Y_2), lipid content (Y_3), protein content (Y_4), energy value (Y_5), viscosity (Y_6) flow behavior index (Y_7) and consistency index (Y_8) of the gruel flour mixture. The first four responses were determined using the nutritional properties of the individual flours present in the flour mixture as shown in Equation 6:

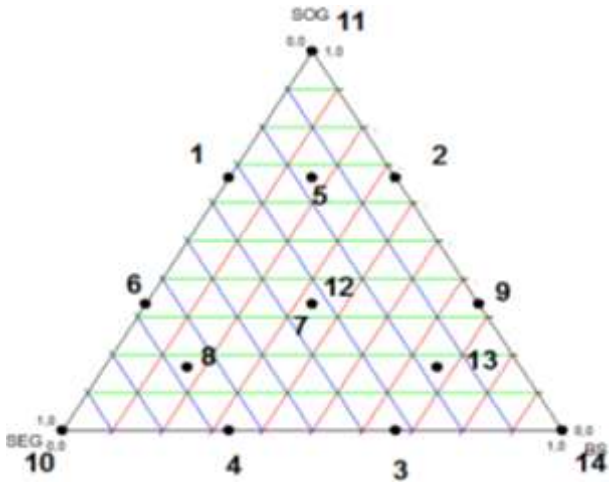

Figure 2. Simplex lattice mixture design experimental points for the effects of malted sorghum (SOG, X1), malted sesame (SEG, X2) and dried banana (BS, X3).

Table 3. Standard values and acceptable range of model validation indicators.

Model validation indicators	Standard values	Acceptable range	References
Adjusted R^2	1	> 80%	Joglekar et May (1987)
AAD	0	[0-0.3]	Baș and Boyac (2007)
Bias factor	1	[0.75-1.25]	Dalgaard and Jorgensen (1998)
Accuracy factor	1	[0.75-1.25]	Dalgaard and Jorgensen (1998)

$$Y_j = \sum_{i=1}^{3} c_i * X_i \quad (6)$$

Y_j $(j = 1, 2, 3, 4)$ are the responses applied to the flour mixture, c_i the content of the different nutritional classes of the i^{th} ingredient and X_i the different factors. Concerning the gruels from different flour mixtures, responses were obtained through physico-chemical analyses. The energy value (Y_5) for the flour mixtures and gruels was calculated as presented in Equation (2), while the viscosity (Y_6), flow behavior index (Y_7) and consistency index (Y_8) of the gruels from flour mixtures were determined using Equations (3), (4) and (5). Since the study involved three dependent factors with no constraints, the experimental domain was the internal surface of an equilateral triangle. The Scheffé matrix, whose simplex network was (3,3) and having 10 initial points was used for the study. Three test points were added as well as a repetition at the center, to verify and ameliorate the precision of the experiments (Mathieu and Phan-than-luu, 2001), making 14 points presented in Figure 2.

Modelling and multi-response optimization

The relationship between the factors and responses was modelled using a polynomial model of the form shown in Equation (7):

$$Y_j = \beta_{1,j}X_1 + \beta_{2,j}X_2 + \beta_{3,j}X_3 + \beta_{12,j}X_1X_2 + \beta_{13,j}X_1X_3 + \beta_{23,j}X_2X_3 + \beta_{123,j}X_1X_2X_3 \quad (7)$$

Y_j $(j = 1 \text{ to } 8)$ are the responses or dependent variable, X_i the factors or independent variables, $\beta_{1,j}$, $\beta_{2,j}$ and $\beta_{3,j}$ the linear factor coefficients, $\beta_{12,j}$, $\beta_{13,j}$ and $\beta_{23,j}$ the quadratic factor coefficients and $\beta_{123,j}$ the cubic factor coefficients. The Statgraphics software, Centurion XV version 15.2.06 (Statpoint Technologies, Inc., Warrenton, VA, USA), was used for modelling, statistical analysis, optimization and plotting. The validation of the models was done by comparing the values of the adjusted coefficient of determination (R^2_{aj}) (Equation 8), the average absolute deviation (AAD) (Equation 9), the bias factor (B_f) (Equation 10), and the accuracy factor (A_f) (Equation 11), to the reference values presented in Table 3.

$$R^2_{aj} = \sum_{i=1}^{n} \frac{(Y_{cal,i} - \bar{Y}_{obs})^2}{(Y_{obs,i} - \bar{Y}_{obs})^2} \quad (8)$$

$$AAD = \frac{\sum_{i=1}^{n} \frac{|Y_{obs,i} - Y_{cal,i}|}{Y_{obs,i}}}{n} \quad (9)$$

$$B_f = 10^{\left(\frac{1}{n}\sum_{i=1}^{n} \log\left(\frac{Y_{cal,i}}{Y_{obs,i}}\right)\right)} \quad (10)$$

$$A_f = 10^{\left(\frac{1}{n}\sum_{i=1}^{n} \left|\log\left(\frac{Y_{cal,i}}{Y_{obs,i}}\right)\right|\right)} \quad (11)$$

Y_{obs} is the observed experimental response, Y_{cal} the predicted response and n the total number of experiments. After validation of the models, analysis of variance (ANOVA) was used to identify the factors or factor interactions, which significantly influence the responses. A factor is significant at 95% interval if its

p-value is less than 0.05. The multi-response optimization was used to determine the factor levels that met the nutritional requirements presented in Table 1. This optimization approach applies to all the experimental designs that use response surface methodology (RSM), which is a mathematical and statistical tool that uses quantitative data to determine an adequate functional relationship between a response of interest and a number of associated control (or input) variables. Such a functional relationship is usually unknown but can be approximated by a low-degree polynomial model (Khuri and Mukhopadhyay, 2010). RSM simultaneously solves multivariate equations, to optimize processes or products as applied in the literature (Sefa-Dedeh et al., 2003; Wang et al., 2007; Fikiru et al., 2016; Kouteu Nanssou et al., 2016). The determination of the factor levels that met the required gruel specifications was done by building the so called «desirability» function based on the values of the responses, which was maximized, minimized or fixed with respect to the objectives of the optimization. In the case of our study, Y_6 was minimized, Y_7 maximized, Y_2 , Y_3 , Y_4 and Y_5 fixed while Y_1 was maximized and minimized. The built «desirability» function was then used to superpose the different responses in order to determine the definitive optimal zone (Statpoint, 2005).

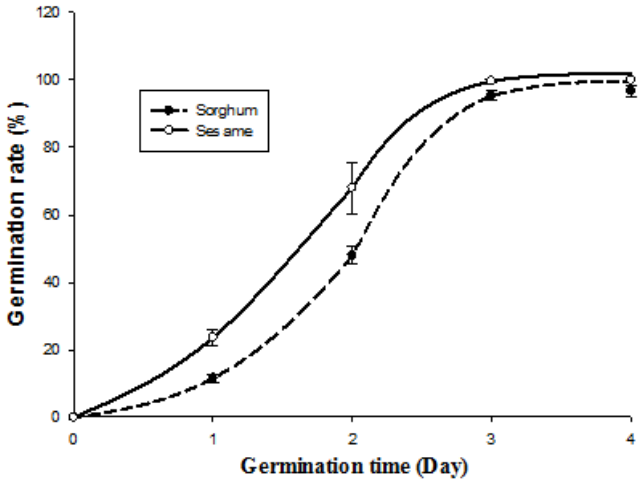

Figure 3. Dynamics of the germination rate of sorghum and sesame grains

RESULTS AND DISCUSSION

Germination of the food products

Figure 3 presents the germination rates of sorghum and sesame grains. The results showed that the germination rates of sorghum grains were higher than those of sesame throughout the germination period, and increased with the germination time to a steady value of 95 and 99% (from the third day), respectively for sorghum and sesame. The results were contrary to that of Hahm et al. (2009), who obtained a steady germination rate for sesame, as from the fourth day at 35°C and in a saturated atmosphere. This observed difference in the germination time could be attributed to differences in germination temperatures and absence of an initial soaking step (24 h soaking at 22°C). In addition, several authors have shown the importance of the soaking step in the efficiency of germination (Eneje et al., 2004; Elkhalifa and Bernhardt, 2010). In essence, the moisture gained by the grains during soaking favours the germination step during which the formation of gibberellic acid is completed. The transportation of the later through the aleuronic layer of the grains induces the production of degradation enzymes (Palmer, 2006) which thus lyses the aleuronic layer and facilitates the expulsion and growth of the radical.

Physico-chemical characteristics of the different flours

Based on our previous study (Maka Taga and Jiokap Nono, 2017), the sorghum and banana carbohydrates occupy more than 77% of the dry matter, followed by proteins (more than 3%), while for sesame, lipids come first (57%) followed by proteins (22%). Germination was observed to have a significant effect ($P<0.05$) on the carbohydrate content of sorghum and on the lipid content of sesame. Compared to total sugars, the soluble sugar contents of all the biological materials were lower. However, the soluble sugar content was observed to be higher after germination, due to the increase in α-amylases activity resulting in a corresponding increase in starch hydrolysis (Elkhalifa and Bernhardt, 2010). The osmotic dehydration applied to banana explained the higher soluble sugar content in the dried fruits compared to the fresh fruits (Jiokap Nono et al., 2002). This is advantageous as the presence of soluble sugars in infant gruel flour increases energy intake of the child (Van Hoan et al., 2010).

The protein content of malted sesame was highest (18.91%) compared to that of dried banana and malted sorghum. All the applied treatments caused a slight, but non-significant decrease in the protein content of all the products. This can be explained by the fact that proteolytic activity increases with germination time, resulting in the production of free amino acids which will be consumed to produce energy required for germination. According to Elkhalifa and Bernhardt (2010), there is also a simultaneous increase in protein synthesis, which justifies the non-significant decrease in protein content observed in sorghum and sesame. For banana, drying at a temperature of about 40°C minimizes protein denaturation (Jiokap Nono et al., 2002).

For sorghum and banana, the effects of treatments on the lipid contents showed a similar tendency to that of protein, but decreased significantly ($p<0.05$) in the case of sesame as presented in Table 4. According to Hahm et al. (2009), the breakdown of lipids and sugars releases energy required for protein synthesis during germination. The low sugar content of sesame (2.59%) however favors the preferential utilization of lipids for

germination while in the case of banana, its lipid content is low and the drying temperature of 40°C limits the lipolytic activity (Cheftel et al., 1983).

The different treatments did not significantly affect the ash content of most of the products. According to Hahm et al. (2009), germination only slightly increases the ash content by increasing phosphorous, sodium and calcium contents. The ash content is not affected by the drying procedure, as they are non-volatile under the experimental temperature used.

Comparison between the properties of the flour mixtures and derived gruels

Table 5 presents the differences in the responses between the flour mixtures and the derived gruels using the various combinations presented by the experimental matrix. The difference (diff 1) between the soluble sugar content of the flours (Y_1 (f)) and those of the derived gruels (Y_1 (b)) for experiments 6, 8, 11, 12 and 13 showed an increase in soluble sugar content of the gruel. This difference increased with the proportion of germinated sorghum (X_1) and could be an important ameliorating factor of the soluble sugar content (Y_1) after cooking. In the case of total sugars, the content also increased in the gruel for all the experimental points, being more significant for experiments 2, 3, 4, 6 and 13 where factor X_3 (dried banana flour) is low (0 - 0.33). This implies factor X_3, associated with other factors could contribute to decrease the total sugar content of the gruel compared to that of the flours (Table 5). The lipid content (Y_3) however decreased for almost all the experimental points particularly for points 2, 3, 10 and 13 where factor X_2 (germinated sesame) is high (between 0.67 and 1). For low values of factor X_2 (between 0 and 0.33), only a slight increase in lipid content was observed (experiments 1, 6, 7 and 9). This tendency could be explained by the high lipid content (50%-db) of factor X_2, favouring interaction (for large quantities of factor X_2) with other components present in the medium, thereby, decreasing its lipid content. The protein content (Y_4) of the gruel increased for all the experimental points, except for point 2 where only factors X_1 and X_2 are present. Concerning the energy value of the gruel (Y_5) it also increased for all the experimental points, except point 10 where only factor X_2 (germinated sesame) was present in the mixture. Factor X_2 has the highest lipid and protein content but the lowest sugar content. Considering the difference in lipid content between the flour and the gruel (diff 3), this factor contributes to the observed decrease in lipid content and since lipids possess the highest energy density, the overall energy value will consequently decrease. This is justified by experiments 5 and 6 having the highest increase in energy value with low proportions of X_2 (between 0 and 0.33).

Model equations, statistical validity and factor effects

Table 6 presents the observed and calculated responses for each experiment of the mixture design and the models for the nutritional, rheological and energy responses are presented in Equations 12 to 19. The models were reduced cubic polynomials whose coefficients express the positive or negative intensity of the factor effects on the corresponding responses. Concerning the rheological responses, the Ostwald de Waele model was used since it showed a good fit (P-values less than 0.01) compared to the Herschel-Bulkley model.

$$Y_1 = 11.047X_1 + 0.377X_2 + 3.468X_3 – 2.432X_1X_2 – 12.546X_1X_3 – 2.904X_2X_3 + 35.519X_1X_2X_3 \quad (12)$$

$$Y_2 = 79.864X_1 + 7.69215X_2 + 85.300X_3 + 78.256X_1X_2 – 8.526X_1X_3 + 60.06_1X_2X_3 – 236.464X_1X_2X_3 \quad (13)$$

$$Y_3 = 2.227X_1 + 41.193X_2 + 0.836X_3 – 4.111X_1\ X_2 – 0.263X_1X_3 – 11.315X_2X_3 + 91.717X_1X_2X_3 \quad (14)$$

$$Y_4 = 10.668X_1 + 20.745X_2 + 4.763X_3 – 11.041X_1X_2 + 2.934X_1X_3 + 0.0845X_2X_3 + 73.532X_1X_2X_3 \quad (15)$$

$$Y_5 = 372.876X_1 + 490.563X_2 + 365.920X_3 + 190.412X_1X_2 + 16.676X_1X_3 + 154.391X_2\ X_3 + 60.788X_1X_2X_3 \quad (16)$$

$$Y_6 = 157.022X_1 + 646.021X_2 + 2851.970X_3 – 912.050X_1X_2 – 4087.650X_1X_3 – 4834.110X_2 + 7007.600X_1X_2X_3 \quad (17)$$

$$Y_7 = 0.566X_1 + 0.327X_2 + 0.126X_3 + 0.149X_1X_2 + 0.364X_1X_3 + 1.212X_2X_3 – 3.276X_1X_2X_3 \quad (18)$$

$$Y_8 = 609.970X_1 + 1943.840X_2 + 8093.410X_3 – 4798.710X_1X_2 – 16721.700X_1X_3 – 20101.500X_2X_3 + 49819.400X_1X_2X_3 \quad (19)$$

Table 7 presents the values of the statistical parameters used for judging the validity of the models. The results show that all the model responses satisfied the validation criteria except the consistency index model (Y_8) that did not respect all the criteria, its accuracy and bias factors could not be calculated due to the negative values present among the predicted values.

In fact, the consistency coefficient models that verify the validation criteria are mostly temperature dependent (Abu-Jdayil et al., 2002; Alpaslan and Hayta, 2002; Razavi et al., 2007) and very few are simultaneous temperature and concentration dependent or only concentration dependent (Alvarez et al., 2008) as in our study. This explains why model Y_8 was not considered for the multi-response optimization. The validated cubic models obtained in this study could therefore be used in theoretical prediction of the nutritional, energy and

Table 4. Proximate composition of the raw materials*.

Substrate	Humidity (g/100g w-b)	Total sugars (g/100g d-b)	Soluble sugars (g/100g d-b)	Lipids (g/100g d-b)	Total proteins (g/100g d-b)	Ash (g/100g d-b)
SON	11.47 ± 0.91^{d}	78.04 ± 10.47^{bc}	1.29 ± 0.10^{b}	1.88 ± 0.86^{a}	6.14 ± 0.27^{a}	0.98 ± 0.02^{bc}
SOG	11.33 ± 1.15^{d}	72.49 ± 2.53^{b}	5.43 ± 0.32^{d}	1.09 ± 0.56^{a}	6.02 ± 0.36^{a}	0.99 ± 0.01^{c}
SEN	3.33 ± 1.15^{a}	2.59 ± 0.64^{a}	0.57 ± 0.11^{a}	57.24 ± 2.39^{c}	21.65 ± 0.52^{b}	0.93 ± 0.04^{a}
SEG	6.00 ± 0.00^{b}	2.40 ± 0.40^{a}	1.02 ± 0.52^{b}	50.71 ± 2.52^{b}	18.91 ± 0.16^{b}	0.95 ± 0.01^{ab}
BF	76.67 ± 1.15^{e}	77.31 ± 11.25^{bc}	3.53 ± 0.76^{c}	0.36 ± 0.13^{a}	3.87 ± 0.98^{a}	0.96 ± 0.01^{ab}
BD	8.44 ± 0.51^{c}	85.37 ± 2.02^{c}	5.75 ± 2.36^{d}	0.46 ± 0.09^{a}	3.06 ± 0.86^{a}	1.00 ± 0.01^{c}

On the same column, data having the same superscript letter are not significantly different at the 5% level. **SON**: non-germinated sorghum; **SOG**: germinated sorghum**; SEN:** non-germinated Sesame; **SEG**: germinated sesame; **BF**: fresh banana; **BD**: dried banana.* : Maka Taga and Jiokap Nono (2017).

Table 5. Experimental design and observed values of the nutritional properties of flours and those of the derived gruels.

Run	Independent variables			Dependent variables (observed values)													
	X_1	X_2	X_3	Y_1(f)	Y_1(b)	Diff 1	Y_2(f)	Y_2(b)	Diff 2	Y_3(f)	Y_3(b)	Diff 3	Y_4(f)	Y_4(b)	Diff 4	Y_5(f)	Y_5(b)	Diff 5
1	0.33	0	0.67	5.64	3.77	-1.87	81.08	83.47	2.39	0.93	1.57	0.64	4.05	6.97	2.92	348.89	375.87	26.98
2	0.33	0.67	0	2.49	2.32	-0.17	25.76	46.12	20.36	34.43	22.96	-11.47	14.61	12.95	-1.66	471.41	482.94	11.53
3	0	0.67	0.3	2.60	0.75	-1.85	30.06	45.96	15.9	33.96	24.51	-9.45	13.63	15.56	1.93	480.37	490.72	10.35
4	0	0.33	0.67	4.17	1.84	-2.33	57.71	69.28	11.57	17.21	12.40	-4.81	8.34	10.34	2	419.12	430.12	11
5	0.17	0.17	0.66	4.91	2.22	-2.69	69.40	73.32	3.92	9.07	8.70	-0.37	6.20	10.00	3.8	384.01	411.54	27.53
6	0.67	0.33	0	3.96	7.47	3.51	49.13	71.86	22.73	18.16	19.28	1.12	10.32	13.88	3.56	401.18	464.50	63.32
7	0.33	0.34	0.33	4.07	2.96	-1.11	53.42	57.93	4.51	17.68	18.06	0.38	9.33	13.03	3.7	410.15	458.40	48.25
8	0.67	0.17	0.16	4.75	7.61	2.86	62.96	71.86	8.9	9.78	8.06	-1.72	7.68	12.10	4.42	370.56	408.34	37.78
9	0.67	0	0.33	5.54	5.35	-0.19	76.78	81.11	4.33	1.41	1.44	0.03	5.03	9.46	4.43	339.93	375.26	35.33
10	0	1	0	1.02	0.37	-0.65	2.40	2.70	0.3	50.71	43.16	-7.55	18.91	21.88	2.97	541.63	486.76	-54.87
11	1	0	0	5.43	10.78	5.35	72.49	81.21	8.72	1.88	1.08	-0.8	6.02	9.72	3.7	330.96	373.46	42.5
12	0.33	0.34	0.33	4.07	5.18	1.11	53.42	61.18	7.76	17.68	15.59	-2.09	9.33	15.25	5.92	410.15	446.03	35.88
13	0.17	0.67	0.16	2.54	3.47	0.93	27.91	61.90	33.99	34.20	27.00	-7.2	14.12	15.14	1.02	475.89	503.16	27.27
14	0	0	1	5.75	3.63	-2.12	85.37	87.08	1.71	0.46	0.22	-0.24	3.06	4.70	1.64	357.86	369.15	11.29

X_1: Germinated sorghum, X_2: Germinated sesame, X_3: Dried banana, Y_1: Soluble sugar content (% db), Y_2: Total sugar content (% db), Y_3: Lipid content (% db), Y_4: Protein content (% db), Y_5: Energetic value (Kcal. (100 gdry matter)$^{-1}$), **f:** flour, **b:** gruel. **Diff**: component difference between flour and gruel.

rheological properties of the gruel flour mixture under different proportions of sorghum, sesame and banana flours. Concerning the influence of the model coefficients, it was also observed that all the linear coefficients ($\beta_1, \beta_2,$ and β_3) were positive, implying the individual factors (X_1, X_2, X_3) had a positive effect on the intensity of the responses.

The quadratic coefficients $\beta_1\beta_2$, $\beta_1\beta_3$ and $\beta_2\beta_3$

Table 6. Experimental design, observed and calculated values of the nutritional and rheological properties of the gruels from flour mixtures.

Run	Independent variables			Dependent variables															
				Y_1		Y_2		Y_3		Y_4		Y_5		Y_6		Y_7		Y_8	
	X_1	X_2	X_3	Obs	Cal	Obs	Cal	Obs	Cal	Obs	Cal	Obs	Cal	Obs	Cal	Obs	Cal	Obs	Cal
1	0.33	0	0.67	3.77	3.21	83.47	81.59	1.57	1.24	6.97	7.38	375.87	371.94	902.40	1045.29	0.38	0.35	566.23	1882.99
2	0.33	0.67	0	2.32	3.39	46.12	49.14	22.96	27.29	12.95	14.93	482.94	493.65	268.80	280.34	0.44	0.44	177.50	432.84
3	0	0.67	0.3	0.75	0.76	45.96	46.91	24.51	25.23	15.56	15.44	490.72	483.32	265.60	307.09	0.53	0.53	551.48	-473.30
4	0	0.33	0.67	1.84	1.79	69.28	72.78	12.40	11.77	10.34	10.11	430.12	441.78	998.40	1042.41	0.47	0.46	126.98	1576.56
5	0.17	0.17	0.66	2.22	3.09	73.32	74.98	8.70	8.09	10.00	2.80	411.54	413.28	1482.00	1148.28	0.32	0.35	3919.73	2519.05
6	0.67	0.33	0	7.47	6.95	71.86	73.20	19.28	14.30	13.88	11.57	464.50	454.42	150.40	117.34	0.51	0.52	259.51	-11.79
7	0.33	0.34	0.33	2.96	4.29	57.93	63.28	18.06	16.41	13.03	13.89	458.40	452.20	304.00	385.23	0.43	0.41	450.79	769.58
8	0.67	0.17	0.16	7.61	6.92	71.86	73.78	8.06	9.39	12.10	11.83	408.34	419.76	176.00	127.65	0.49	0.48	277.90	52.57
9	0.67	0	0.33	5.35	5.73	81.11	79.78	1.44	1.70	9.46	9.35	375.26	374.26	198.40	146.97	0.49	0.50	350.16	-611.49
10	0	1	0	0.37	0.38	2.70	7.69	43.16	41.19	21.88	20.74	486.76	490.56	668.80	646.02	0.32	0.33	1618.05	1943.84
11	1	0	0	10.78	11.05	81.21	79.86	1.08	2.23	9.72	10.67	373.46	372.88	128.00	157.02	0.57	0.57	199.37	609.97
12	0.33	0.34	0.33	5.18	4.29	61.18	63.28	15.59	14.41	15.25	13.89	446.03	452.20	259.20	385.23	0.38	0.41	69.76	769.58
13	0.17	0.67	0.16	3.47	2.39	61.90	43.41	27.00	27.94	15.14	16.63	503.16	490.08	342.40	309.94	0.47	0.43	849.04	437.86
14	0	0	1	3.63	3.47	87.08	85.30	0.22	0.83	4.70	4.76	369.15	365.92	2806.40	2851.97	0.13	0.13	8575.15	8093.41

X_1: Germinated sorghum, X_2: Germinated sesame, X_3: Dried banana, Y_1: Soluble sugar content (% db), Y_2: Total sugar content (% db), Y_3: Lipid content (% db), Y_4: Protein content (% db), Y_5: Energetic value (Kcal. (100 gdry matter)$^{-1}$), Y_6: Viscosity (mPa.s), Y_7: Flow behaviour index (dimensionless), Y_8: Consistency index (mPa.s^n), [a]Obs: Observed value; Cal: Calculated value.

Table 7. Statistical parameters for model validation.

Validation parameters	Calculated parameter values							
	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8
R^2aj	88.31	86.78	94.71	86.74	94.99	95.61	94.93	75.62
AADM	0.16	0.18	0.37	0.11	0.01	0.18	0.06	2.54
Bf	1.01	1.07	1.13	0.91	1.00	0.99	1.01	-
Af	1.17	1.14	1.20	1.16	1.01	1.19	1.06	-

showed a similar tendency in the case of responses Y_5 and Y_7, while for responses Y_1,Y_3,Y_6 and Y8 they were all negative implying the quadratic interactions (X_1X_2, X_1X_3 and X_2X_3) had a negative effect on the intensity of the responses.

The quadratic coefficients for responses Y_2 and Y_4, showed both positive and negative values implying they had both favorable and unfavorable effects on the responses. For the cubic coefficients, they were all positive, except for responses Y_2 and Y_7 where they had negative values.

Multi-response optimization

The factor combinations that simultaneously optimize the responses were obtained by maximizing the desirability function. The experimentally obtained minimum and maximum points, and desired responses are presented in Table 8. The results show that the zone of the desired values was included in that of the experimental values, which would have otherwise rendered the multi-response optimization impossible. Figure 4 shows

Table 8. Minimum and maximum observed values and Optimal combination of factors and responses.

Units	Responses	Observed values		Calculated Optimum		Desired values	
		Minimum	Maximum	Minimum constraints	Maximum constraints	Minimum	Maximum
g/100 g db	Soluble sugars	0.37	10.78	4.67	5.11	Minimize	Maximize
	Total sugars	2.70	87.08	66.77	63.25	25	70
	Lipids	0.22	43.16	13.72	17.59	10	18
	Proteins	4.70	21.88	13.15	13.99	12	22
Kcal/100 g db	Energetic value	369.15	503.16	439.22	459.49	400	
cP	Viscosity	128.0	2806.4	381.18	239.36	-	1000
Dimensionless	Flow behavior index	0.1701	0.9114	0.409	0.431	Maximize	
Dimensionless	Desirability		-	0.517	0.598	0	1

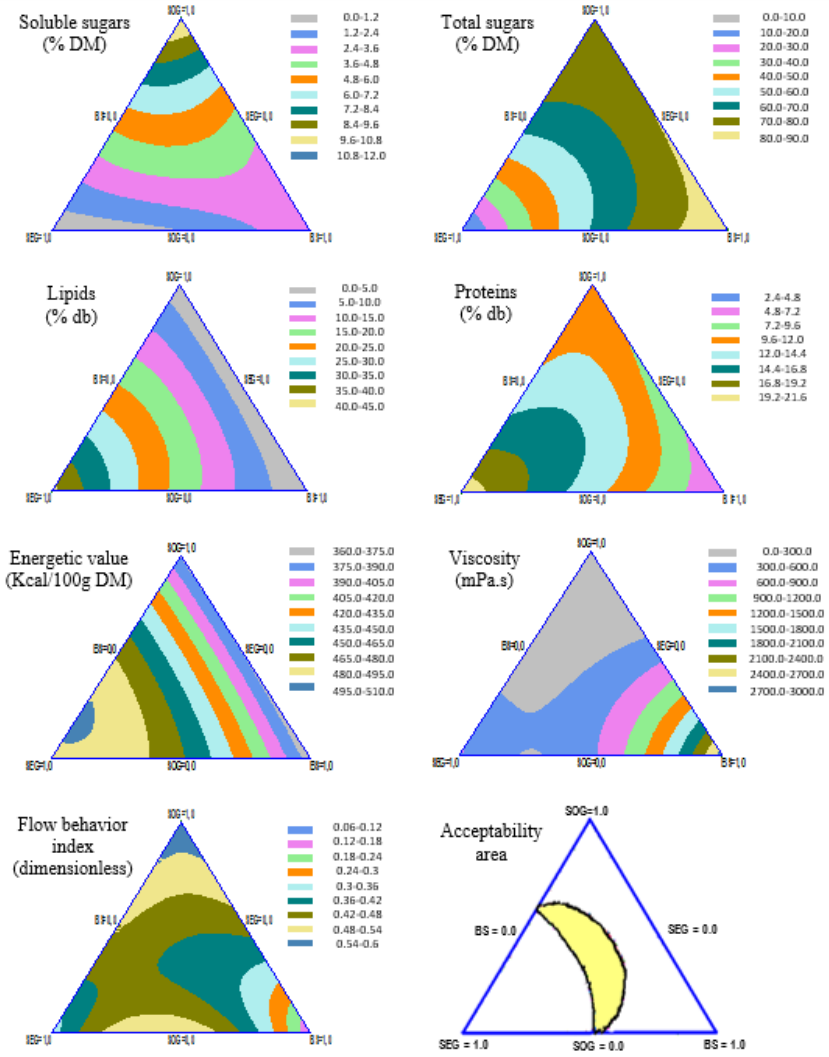

Figure 4. Ternary contour plots showing the effects of factors on the nutritional, rheological and energetic responses properties and the obtained acceptability area (obtained by superposing the contour plots of soluble sugars, total sugars, lipids, proteins, energetic value, viscosity and flow behavior index) that respects the desired gruel properties.

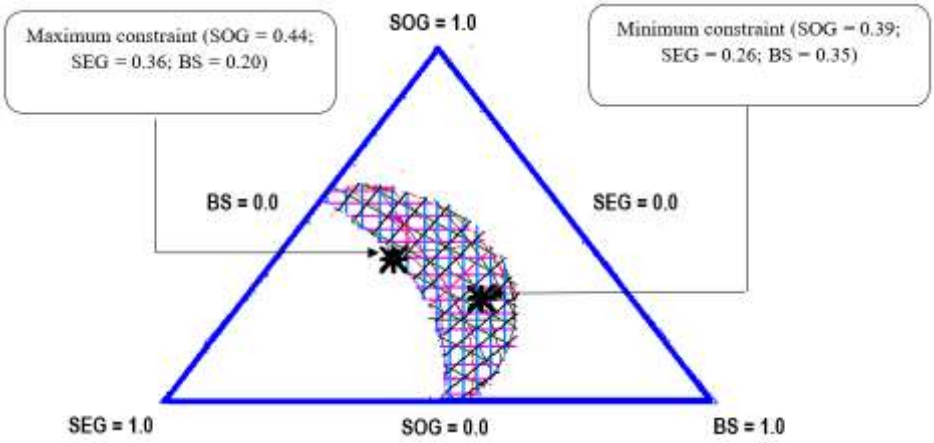

Figure 5. Maximum and minimum constraints of the gruel flour mixture located in the acceptability area.

Table 9. Optimal combinations, real and theoretical.

Units	Responses	Theoretical values	Real values	χ^2_{data}	$\chi^2_{\alpha=0.05}$
g/100 g db	Soluble sugars	4.77	6.03	6.74	12.59
	Total sugars	62.31	66.7		
	Lipids	17.76	16.38		
	Proteins	14.18	13.97		
Kcal/100 g db	Energetic value	460.69	458.09		
cP	Viscosity	261.40	204.80		
Dimensionless	Flow behavior index	0.695	0.749		

the contour plots of the different cubic models of the responses. The desirability function obtained was used to superpose the contour plots and determine the acceptable zone that respects the gruel flours specifications as shown in Figure 4 (acceptability area).

Table 8 presents the calculated optima of the gruel flour mixture, which contain respective sorghum, sesame and banana flour proportions of 0.44, 0.36 and 0.20 for the maximum constraint values and 0.39, 0.26 and 0.35 for the minimum constraint values. These two points are presented in Figure 5 and give an indication of the practical points, which could be applied. It represents factor proportions comprised between 0.39 and 0.44, 0.26 and 0.36 and 0.20 and 0.35 respectively for sorghum, sesame and banana flours.

Table 9 presents the experimental and predicted responses using an arbitrary point chosen from the acceptability area. Using the independence test at a 5% significance level, there was no difference between the experimental and predicted values. The predefined acceptability area can therefore be used for the formulation of infant flour using sorghum, sesame and banana.

Conclusion

The overall objective of this study was achieved by the successful formulation of a gruel flour mixture from sorghum, sesame and banana, which respects the norms in terms of rheological, nutritional and energy properties. The physico-chemical and rheological characteristics of the different ingredients were investigated and mixture design was presented as a valuable tool for determining the optimal mixing proportions of the factors. A standard protocol for producing the gruel flour mixture was also presented, including malting as an essential step for nutrient enhancement. Based on the results, the optimal proportions established for the gruel flour mixture were comprised between 0.39 and 0.44, 0.26 and 0.36 and 0.20 and 0.35 respectively for sorghum, sesame and banana flours. Since the study involved locally available food products, it is concluded that the protocol and results obtained can satisfactorily be applied for local production of gruel flours respecting the norms, thereby mitigating the inconveniences associated with imported flours. As perspectives, an associated techno-economic analysis should be carried out to further evaluate the

economic viability of implementing such a project on a large scale.

CONFLICTS OF INTERESTS

The authors have not declared any conflict of interests.

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Process improvement for mechanical extraction of low-viscosity clear banana juice

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Low-viscosity clear banana juice is traditionally produced using a rudimentary mechanical process of kneading a mixture of ripe high-tannin banana and grass. The aim of this study was to come up with a new efficient and hygienic process that does not require use of grass. According to a new process, peeled ripe high-tannin Pisang Awak banana fingers were mashed in a blender, without addition of grass, until pulp agglomeration occurred. The mashed pulp was pressed to separate clear banana juice. The process successfully produced clear banana juice with low-viscosity (1.85×10^{-3} Pa.s), high content of dissolved solids (27 - 28°Brix), and average density of 1120 kg.m^{-3}. Juice yield increased with mashing time up to 60% (w/w), and degree of ripeness until fruit colour was mostly yellow, but juice extraction failed for overripe banana. Condensed tannins decreased with ripening and juice extraction was possible as long as condensed tannin concentration was above 0.68% (w/w) of peeled banana. Therefore, low-viscosity clear banana juice can be produced in a more hygienic condition using the new process.

Key words: Clear banana juice, Pisang Awak, mechanical banana juice extraction, condensed tannins.

INTRODUCTION

Extraction of low-viscosity clear banana juice has always been a challenge. While a standard process of preparing many varieties of low-viscosity fruit juices involves pulping and pressing resulting pulp, the process results in a viscous puree when applied to ripe banana. A number of methods for obtaining low-viscosity clear banana juice such as enzymatic maceration of ripe banana pulp, hot water extraction, as well as a combination of the two have been investigated (Lee et al., 2006; Surendranathan et al., 2003; Minatchy et al., 2007). In most cases banana juice extracted using enzymatic or hot water extraction methods is cloudy, and the processes are expensive due to high cost of enzymes and energy requirement (Byarugaba-Bazirake, 2008; Kyamuhangire et al., 2002;

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Surendranathan et al., 2003).

However, low-viscosity clear banana juice has been extracted using indigenous mechanical method for several centuries, and the process has remained virtually the same in Eastern and Central African countries (Kyamuhangire, 1990; Kyamuhangire et al., 2002; Kyamuhangire and Pehrson, 1999; Kasozi and Kasisira, 2005). The indigenous extraction process entails kneading by hands or feet a mixture of ripe banana fingers and grass, usually spear grass (*Imperata cylindrica*), until pulp gets entangled within grass matrix, allowing clarified juice to separate from pulp (Kasozi and Kasisira 2005; Kyamuhangire et al. 2002; Wilson et al. 2012). There have been a few improvements to the indigenous process: grass has been replaced by plastic fibres, hand and foot have been replaced by dough kneading machine or new mechanical systems (Kyamuhangire et al. 2002; Kasozi and Kasisira 2005; De Beer and Sigawa 2008). The improvements have not eliminated grass or fibres used during juice extraction.

Mechanism for releasing low-viscosity banana juice remains unclear and is more complicated than simple mastication and pressing. Apparently, low-viscosity banana juice can be extracted from high tannin content bananas (Gensi et al., 1994; Kyamuhangire and Pehrson, 1999; Kyamuhangire et al., 2002), most of which are East African Highland Banana (EAHB) (Musa AAA-EA genotype) and Pisang Awak (Musa ABB genotype) (Kyamuhangire and Pehrson, 1999; Kyamuhangire et al., 2006). Tannins, in particular condensed tannins are known to form insoluble complexes with protein and polysaccharides (McManus et al., 1981; McManus et al., 1985; Hagerman and Butler, 1981; Obreque-Slier et al., 2012; Ozdal et al., 2013; Naumann et al., 2014; Bilgener, 2015). In a microstructure study, juice-producing bananas were found to contain more and larger tannin laticifers embedded within their pulp than non-juice-producing banana (Kyamuhangire et al., 2006). In light of the above, high tannin content in banana was identified as a key factor for the mechanical extraction of low-viscosity clear banana juice. Hence, it was hypothesised that releasing tannins from laticifers and mixing it with the rest of the pulp could facilitate formation of tannin-protein insoluble complexes and consequently juice separation from the pulp. Objective of this study was to extract low-viscosity clear banana juice by mashing ripe peeled Pisang Awak, so as to split and release tannins from laticifers, and mix it with proteins and pectin in order to facilitate formation of insoluble aggregate, resulting in juice separation without using extraction aids such as grass, fibres or enzymes.

MATERIALS AND METHODS

Mature Pisang Awak bananas were purchased from a local market in Dar es Salaam, Tanzania and ripened at ambient temperature in an open space until colour of banana finger turned black within 5 days in a Food Laboratory, Department of Chemical and Mining Engineering, University of Dar es Salaam, Tanzania. Chemical reagents used in this study were of analytical grade from Carlo Erba, Milano, Italy.

Juice preparation

Ripe banana fingers were peeled, sliced to approximately 3 cm thick discs. A batch of sliced banana weighing 300 g, was mashed in a blender (Russell Hobbs, Johannesburg, South Africa). A prolonged mashing was carried out while observing for changes of flow characteristics of pulp. Once sliced banana changed to homogeneous viscous puree, followed by a mixture of semi-solid pulp and low-viscosity clear banana juice, the mixture was removed from blender, wrapped in a cotton cloth and hand-squeezed to separate the juice. Juice volume and weight were recorded using a 250 mL measuring cylinder and analytical balance, respectively. Degree of ripeness of banana was visually assessed in terms of colour of unpeeled banana fingers and in terms of firmness of peeled banana fingers using fruit penetrometer (GY-3, Yueqing Handpi Instruments Co., Ltd., Yueqing, Zhejiang, China). Effect of mashing time on juice yield was assessed using bananas whose ripeness was mostly yellow, a degree of ripeness that had been identified to provide the maximum juice yield. Effect of degree of ripeness on juice yield was assessed by mashing banana of various degree of ripeness for 20 min, an extraction time that had been identified to provide more than 98% of the maximum juice yield. Juice dissolved solids were measured with a temperature compensation hand-held refractometer (MT-032ATC, Three-In-One Co., New Taipei City, Taiwan), with a measuring range of 0 to 32° Brix and 0.2% accuracy.

Tannin assay

Condensed tannins in ripe banana, spent pulp and juice were determined according to dry sample Butanol-HCl assay by Makkar (2003), with modification to accommodate wet samples. Condensed tannins were extracted by grinding 200 mg wet samples of fresh banana and spent pulp with laboratory ceramic mortar while slowly adding up to 5 mL of 70% aqueous acetone. The mortar was rinsed with up to 5 mL of 70% aqueous acetone and the mixture was sonicated in a 50 mL beaker suspended in chilled water (10°C) at 30% amplitude and 20 kW for 20 min with ultrasonic processor, UP200St (Hielscher, Teltow, Germany). Banana juice was directly used as a tannin extract. Extract contents were transferred to test tubes, cooled on ice and centrifuged for 10 min at 3000 g with Axiom 800 (Axiom, Bürstadt, Germany). From the tannin extract 6 mL was transferred into a test tube, followed by 3 mL of Butanol-HCl (butanol-HCl 95:5 v/v) and 0.1 mL Ferric reagent (2% ferric ammonium sulphate in 2N, HCl). The tube was vortexed to ensure proper mixing, covered with Teflon-lined plastic screw cup and placed in a boiling water bath for 60 min. For each sample a blank of unheated tannin extract and reagent mixture was prepared. The tube was cooled to room temperature and absorbance was measured at 550 nm using Milton Roy Spectronic 21D spectrophotometer. The absorbance of corresponding blank was subtracted from sample absorbance to eliminate absorbance of unheated mixture. Condensed tannins as leucocyanidin equivalent were calculated using equation (1) Makkar (2003):

$$\%\ Condensed\ tannins = Absorption\ at\ 550\ nm\ x\ 78.26\ x\ Dilution\ factor \quad (1)$$

Where dilution factor = 0.5 mL/(Volume (in mL) of extract used for assay). Condensed tannins were assayed twice (morning and evening) a day.

Table 1. Properties of banana juice produced my mechanical process.

Properties	Value
Juice average density (kg.m^{-3})	1120
Total Dissolved solids (^{o}Brix)	27 - 28
pH	4.5 - 4.7
Viscosity (Pa.s)	1.85×10^{-3}

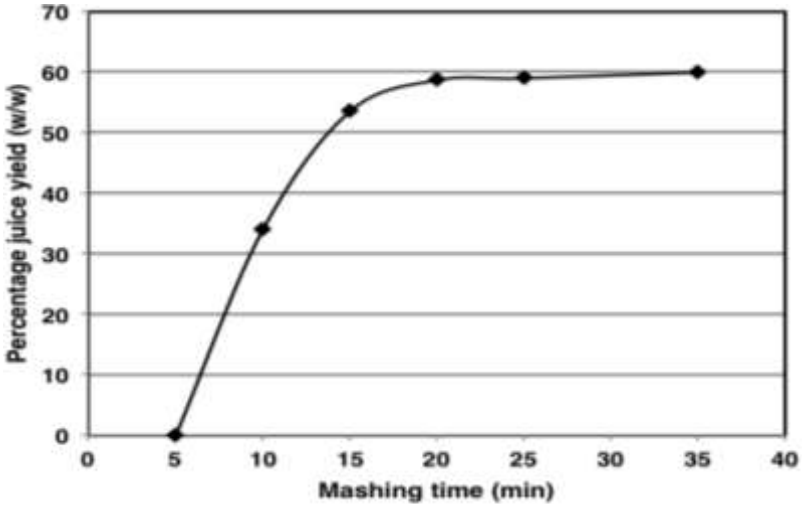

Figure 1. Variation of juice yield with mashing time.

RESULTS AND DISCUSSION

Low-viscosity clear banana juice was successfully extracted without using grass, fibres or enzymes. During mashing, sliced banana fingers formed a creamy homogenous viscous puree; with prolonged mashing, the puree was transformed to a semi-solid pulp of two mixed phases: Insoluble agglomerates and a crystal clear liquid juice. Transformation was observed within 5 to 35 min of mashing depending on degree of ripeness. The juice oozed out when the mixture was left undisturbed. Fast juice separation was achieved by manually squeezing the mixture in a clean cotton cloth. Pressing pulp/puree that had not gone through a transformation to the two phases did not release the juice. Properties of the juice are indicated in Table 1. Mashing time and degree of ripeness affected juice yield and overall juice extractability depended on content of condensed tannins in the banana.

Effect of mashing time on juice yield

Effect of mashing time on juice yield was investigated when banana had attained a complete yellow colour, which was equivalent to a fruit firmness of 1.8×10^{5} N.m^{-2}. Two phase formation phenomenon accompanied by juice separation commenced within 5 min of mashing (Figure 1). Prolonged mashing resulted in higher juice yield which reached 59% (w/w) after 20 min and 60% (w/w) after 35 min. Kyamuhangire et al. (2002) obtained juice yield of 54.1% after 20 min from Pisang Awak mixed with plastic fibre using dough mixer. De Beer and Sigawa (2008) reported 50% juice yield from Pisang Awak and Kasozi and Kasisira (2005) reported much lower juice yield of 31%. In both cases, mechanical juice extractors were employed. Juice yield was comparable to 55.6 to 64.8% (w/w) for juice produced by mechanical and enzymatic method from Pisang Awak (Kyamuhangire et al., 2002; Byarugaba-Bazirake, 2008).

Effect of degree of ripeness on juice yield

Degree of ripeness was measured in terms of fruit firmness. Within five days or ripeness, fruit firmness decreased from 3.5×10^{5} N.m^{-2} for greenish yellow banana to 0.9×10^{5} N.m^{-2} for overripe, black-coloured banana (Figure 2).

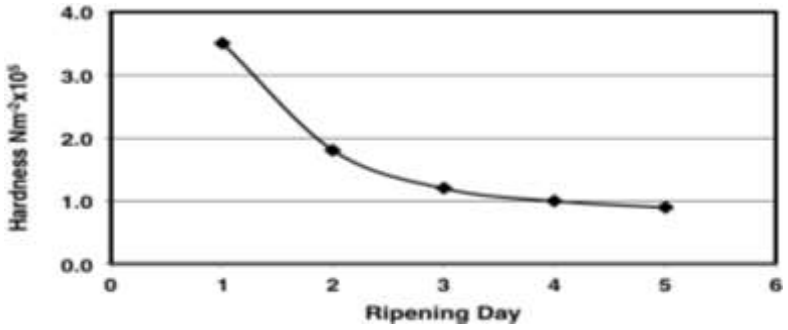

Figure 2. Variation of fruit firmness with degree of ripeness.

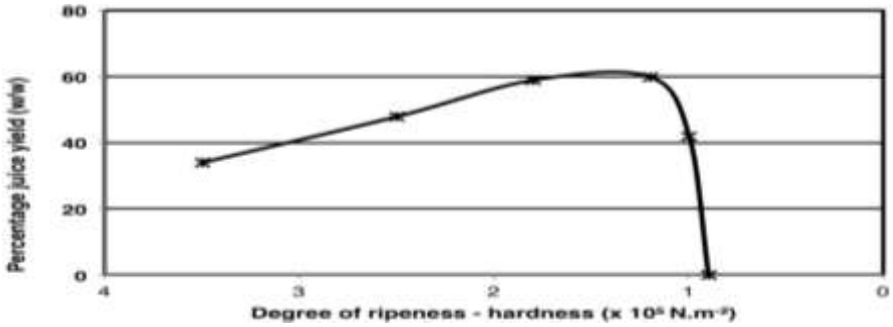

Figure 3. Variation of juice yield with degree of ripeness.

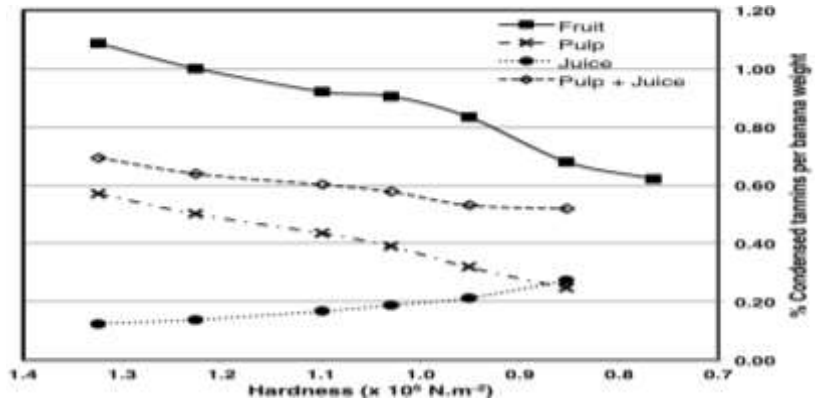

Figure 4. Variation of condensed tannins with degree of ripeness.

Juice yield increased with degree of ripeness (that is, with decreasing fruit firmness) from 34% (w/w) to maximum yield of 58% as fruit firmness decreased from 3.5×10^5 $N.m^{-2}$ to 1.2×10^5 $N.m^{-2}$, respectively as shown in Figure 3. Thereafter, juice yield decreased with fruit firmness and extraction failed when fruit firmness reached 8.5×10^6 $N.m^{-2}$. Maximum juice yield was obtained when banana fingers were mostly yellow, a ripeness stage that coincided with a release of strong ripe banana sweet flavour.

Variation of condensed tannins and their effect on juice extraction

Condensed tannin, a necessary fruit component for mechanical extraction of banana juice was monitored in peeled banana fingers, spent pulp and juice, and expressed as weight percentage of peeled banana, within fruit firmness of $1.3\text{-}0.77 \times 10^5$ $N.m^{-2}$ as shown in Figure 4. Based on the method used, condensed tannins decreased with ripening from 1.09 to 0.68% in peeled

banana fingers and 0.57 to 0.25% in spent pulp, but increased in juice from 0.12-0.27%. Decrease of tannins with ripening happens in many fruits and is known to be a result of polymerisation of tannins (Barnell and Barnell, 1945; Goldstein and Swain, 1963; Obreque-Slier et al., 2012). As condensed tannins diminish, so does the extent of tannin-protein complex formation, hence undesirable for mechanical extraction of banana juice. This explains why juice extraction failed when condensed tannins decreased below 0.68% in peeled banana. A similar trend of higher tannins in spent pulp than in juice was observed by Kyamuhangire et al. (2006) during mechanical extraction of banana juice using a dough mixer.

Higher quantities of tannins in spent pulp than in juice tend to support a hypothesis that condensed tannins are involved in formation of insoluble tannin-protein/polysaccharide complexes resulting in juice release. It was not clear why condensed tannins increased in banana juice with ripening; the matter remains the subject for further study. Quantity of condensed tannins in banana fingers was higher than corresponding combined quantities in the spent pulp and the juice. Kyamuhangire et al. (2006), using a different tannin quantification method, obtained similar results whereby tannin quantity in Pisang Awak fruit was more than combined quantities of tannins in spent pulp and juice. The difference is likely due to acceleration of natural tannins reduction process that is usually slow during fruit ripening.

Conclusion

The new banana juice extraction method is better and superior than the indigenous banana juice extraction technology and its mechanical variants. It is now possible to extract low-viscosity clear banana juice exclusively by a mechanical method without addition of grass or fibres. The mechanical banana juice extraction process is possible only if there were sufficient condensed tannins in banana. Mechanism for tannin-protein/polysaccharide interaction during mechanical banana juice extraction will be a subject for future study.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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