PHYSICO-CHEMICAL, NUTRITIONAL AND SENSORY QUALITIES OF CASSAVA-WHEAT SEMOLINA MACARONI NOODLES

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DEDICATION

This project is dedicated to the Almighty God Jehovah, who watches over me both day and night, guiding my steps, protecting my very life, granting me divine favour throughout the course of this study

and

The loving family setting he provided for me: my parents: Mr and Mrs J.O. Awowade; My darling husband, Ejide along with my wonderful children: Ayoola. Oluseye and Eniola for their great sacrifice, understanding and loving support all these while.

ABSTRACT

Noodles are popular foods worldwide because of their unique sensory properties, shelf stability, simplicity of preparation and low costs. The demand for these products traditionally made from Durum-Wheat Semolina (DWS) has increased tremendously; hence, the need to utilize locally available tropical root crops in the development of such products. This study was undertaken to evaluate the potentials of using cassava – wheat blend in the production of macaroni noodles.

High Quality Cassava Starch (HQCS) from improved low-cyanide cassava variety (TMS 30572), was mixed with DWS in pre-determined ratios to produce flours containing 0, 20, 30, 50, 70 and 100% HQCS. These were analysed for chemical composition (proximate, sugar, cyanide) and physico-chemical properties (pasting, amylose, water binding capacity, starch damage, α-amylase activity, dough mixing stability) by AOAC and American Association of Cereal Chemists' approved methods. Macaroni noodles were produced from the flour samples mixed with 5.0% soya flour. Effects of the six levels of HQCS inclusion and variation in hydration levels (45.0, 50.0 and 55.0%) on dough and macaroni were determined using a randomized complete block factorial design. Macaroni composition (proximate, energy, sugar, mineral profile), physico-chemical properties (pasting, amylose, cooking losses), microbiological quality and sensory characteristics (preference and difference tests) of the noodles were also evaluated using standard procedures. Data were analysed using propriety software.

Blends of HQCS and DWS had moisture, protein, fat and ash contents ranging from 10.4-11.6%, 0.8-12.1%, 1.0-4.4% and 0.1-0.8%, respectively. Protein content of flour blends and dough mixing stability decreased with increasing levels of HQCS. Cyanide levels in all the flour samples were less than 0.1 ppm and α-amylase activity was greater than 200. The DWS and HQCS samples had similar pasting temperatures (50.2^{o}C). Other pasting properties of flour samples including peak viscosity, holding strength, breakdown and final viscosities increased with increasing levels of HQCS. Developed macaroni noodles had 5.3-14.2% protein, 3.8-5.1% fat, 1.5-2.1% ash at 0 to

80% DWS inclusion; and also 70.3-82.8% carbohydrate and 383.9-386.4 kcal/100g energy between 20 and 100% levels of HQCS inclusion. Addition of soya flour to the blends during macaroni production increased protein content of the noodles. Iron and calcium contents increased from 28.9 to 72.0 and 627.5 to 819.1 mg/kg, respectively as HQCS inclusion increased from 20 to 70%. Microbial load (6.83×10^3 - 3.33×10^4 cfu/g) was within acceptable limits and no organism of public health significance was detected. The inclusion of HQCS reduced cooking time from 11 to 7 min, but increased solid and soluble cooking losses. The correlation between final pasting viscosity and total cooking loss was significant ($r = 0.9$; $p<0.05$). Inclusion of HQCS, hydration levels and their interactions, had significant effect ($p<0.01$) on macaroni cooked weight, water absorption index, swelling volume, solid and soluble losses. The acceptable macaroni were those containing 30 and 50% HQCS, beyond which cooking and sensory properties were adversely affected.

New macaroni noodles with acceptable sensory, physico-chemical, nutritional and microbiological qualities were developed from cassava–wheat blends. Calcium, iron and energy contents of macaroni were improved, thus enhancing cassava utilization.

Keywords: Macaroni, Cassava starch, Durum wheat semolina, Hydration,
Physico-chemical properties.

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CERTIFICATION

This is to certify that this research work was carried out by Oladunmoye Olufunmilola Olaitan (Mrs.) in the Department of Food Technology, University of Ibadan, Nigeria.

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FMNIFST, MIFT, AIDFST

LIST OF ABBREVIATIONS

COSCA	Collaborative Study of Cassava in Africa
CWSMN	Cassava –wheat semolina macaroni noodles
DWS	Durum Wheat Semolina
FAO	Food and Agricultural Organisation
FIIRO	Federal Institute of Industrial Research, Oshodi
GCDS	Global Cassava development Strategy
HQCS	High Quality Cassava Starch
IDEAA	Initiative for Development and Equity on African Agriculture
IDRC	International Development Research Centre
IFAD	International Fund for Agricultural Development
IFPRI	International Food Policy Research Institute
IITA	International Institute of Tropical Agriculture
NCRP	National Coordinated Research Project
NEPAD	New Partnership for Africa’s Development
NFTS	Nigerian Foreign Trade Summary
NRCRI	National Root Crops Research Institute
RVA	Rapid Visco Analyses
SON	Standards Organisation of Nigeria
TMS	Tropical Manihot Series
UNICEF	United Nations International Children Emergency Fund

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CHAPTER ONE

INTRODUCTION

INTRODUCTION

Increasing urbanization in African countries and the stress and rigor of daily living are changing the food habits and preference of many towards convenience food products, which are easy to prepare, transfer and store. Noodles are only second to bread in popularity as staple food in developed and developing countries. They are nutritious and delicious, containing complex carbohydrates, which can provide longer lasting energy and help to feel fuller for longer periods. Noodles/Pastas have thus become a global food, consumed in all five continents, with increased awareness of its nutritional benefits (Sissons, 2008).

Noodles are convenient pasta products basically prepared from unleavened doughs of durum wheat semolina (Baiano *et al*., 2008). The terms 'Noodle' and "Pasta" are often used synonymously, and the products are marketed under different trade names, often based on their extruding shape(s). These include: tubular macaroni, long rods spaghetti, thin short rods vermicelli, spiral ravioli, to mention only a few (Sowbhagya and Zakiuddin, 2001). In addition to these dried noodles, there are steamed, deep-fried wave shaped thin rods, named instant noodles. These are packaged in bags, bowls or in cups (Kim, 1996).

Noodles have long been a favourite of Chinese and Mediterranean civilizations, but are now currently consumed and appreciated worldwide (Feillet *et al*., 1996). They are a major food in the Philippines and an industrial product in China. Northern China considers them a staple food whereas they are eaten as a snack food in Southern China (Huang, 1996). Koreans, just like Africans eat instant noodles as a meal while the Japanese view them as an in-between meal (Kim and Lee, 1989). In some African countries like Zambia, noodles are consumed either as a snack or an in-between meal while in countries like Nigeria; they are considered a meal especially when consumed alongside rice (Oladunmoye *et al*., 2004).

In view of the increasing popularity of convenience food products, it has been observed that there is a growing market for noodle products in Nigeria. A report by the Nigerian Foreign Trade summary (2006) showed that in 2006 alone, total pasta imported (such as spaghetti, macaroni, couscous, etc.) was estimated to be 11,649,809 kg at ₦62, 357,450. In the recent past, certain companies in Nigeria were re-packaging imported fried noodles for sale in the market. For instance, Indomie instant noodles were distributed in Nigeria by Panabiz International Limited under the Licence of PT. Indo-food sukses makmur, Indonesia. Presently, there exist four companies producing noodle products in Nigeria. These include Dangote group of companies which produces spaghetti (long grain noodles); De United Food Industries Limited, producing indomie instant noodles (fried), Nigerian Flour Mills and Honeywell Flour Mills producing both *spaghetti* and *macaroni* (short tubular noodles). So far, these pasta products existing in Nigerian markets are made from 100% durum wheat semolina, which is imported into the country.

The increasing consumption and demand for wheat in Nigeria was largely due to increase and expansion in bread and pasta industries, and for the manufacture of crackers, noodles etc (Anonymous, 2006). Presently, domestic wheat demand in the country is far more than local production; consequently 90-95% of wheat consumed is imported from the United States of America. For example, the country imported 4.3 million tons of wheat in 2007 as against 3.8 million tons in 2006 (Falaki and Mohammed, 2011), from countries such as China, Indonesia, Italy, Brazil, Germany, France, Holland, USA, and the United Kingdom. Hence, much effort to boost local production of wheat is needed to stem Nigeria's rising import bills for the crop which is N6 billion annually (Anonymous, 2008). Production data on Nigeria grown wheat is scanty. The Minister of Agriculture, Dr. Akinwunmi Adesina, while addressing stakeholders on Cassava Value Chain Development in Nigeria, at International Institute of Tropical Agriculture (IITA) in Ibadan, Oyo State, disclosed that, in 2010 alone, Nigeria spent N635 billion on importation of wheat and N356 billion on importation of rice (Osagie, 2011).

A two-year trial was conducted during the 2001/02 and 2002/03 dry seasons at Kadawa (lat. 110 39'N, long. 080 27'E and 500 m above sea level) to evaluate the performance of twelve durum wheat varieties (Falaki and Mohammed, 2011). The investigation was aimed at identifying promising durum wheat varieties introduced from Mexico, with superior adaptation to the local growing conditions in the Sudan savannah ecological zone of Nigeria.

In sharp contrast, Nigeria is the worlds' largest producer of cassava. In this century, cassava has been earmarked as the crop that can spur rural industrial development and raise income for producers, processors and traders. Cassava is the chief source of dietary food energy for the majority of the people living in the lowland tropics, and much of the sub-humid tropics of West and Central Africa. Therefore, its production and utilization must be given prime attention in food policy. Adoption of high yielding varieties and the increase production have shifted the problem of the cassava sector from supply to demand issues, such as finding new uses and markets for cassava (Echebiri and Edaba, 2008). Increased utilization would lead to a reduction in annual post harvest losses usually incurred on cassava roots as well as broaden our food base and provide household food security for both rural and urban population (IITA, 2002). Comparing the output of various crops in Nigeria, cassava production is the highest, followed by yam production at 27 million tonnes in 2002, sorghum at 7 million tonnes, millet at 6 million tonnes and rice at 5 million tonnes (FAO, 2004a). Cassava contributes to the food security status of its producing and consuming households (Plucknett *et al*., 2000).

Cassava-based products have a considerable potential to substitute imported cereals and thus save foreign exchange. Bokanga (1998) reported that cassava was being increasingly used as composite with wheat flour in many food preparations such as bread, snacks, and other confectionaries in Nigeria. Nigerian Federal Government Policy stipulated that all flour produced in Nigeria must contain 10% cassava (CTA, 2005). In a similar vein, a fair comparison of the diets of Africans to Asians and Europeans made Oyewole (2002) to infer that *'Cassava is to Africans what Rice is to Asians and what Wheat is to Europeans'*. This is a good platform on which the production of noodle products from cassava can be launched for the benefit of the African continent.

To this end, product development research on cassava utilization needs to be strongly promoted, particularly in Nigeria; and generally all over Africa. Much attention need to be ascribed to raw material import substitution, promotion of a positive image for cassava, development of products for existing and new markets, identification of the functional characteristics of cassava genotypes in relation to various end uses, utilization of cassava plant parts i.e. the peel and leaves for livestock feeding. Also, suitability of cassava leaves as vegetable, determination of foliage yield and digestibility for human and animal nutrition, investigations into the impact of pathogens and saprophytes on the quality of stored cassava products, including contaminations with mycotoxins (Plucknet *et al*., 2006).

In a UNICEF/IITA programme, cassava was viewed as a means of attaining household food security, increasing food availability and maximising indigenous utilization of locally available crops (Onabolu, 1988). Low cyanide variety (sweet cassava) was observed to meet these criteria and was thus suggested to be a good substitute for wheat flour in imported products. Hence, with focused encouragement and sustained research and development, cassava can make substantial contributions to the broad goals of food security, poverty alleviation, equity and protection of the environment (Hershey and Guy, 1997).

Although, cassava lacks gluten, which is the wheat protein fraction that imparts certain unique characteristic behaviour to wheat dough; its starch matrix exhibits visco-elastic properties. This needs to be technologically modified to suit cassava noodle production. Appropriate processing technologies need to be developed and processing operations and conditions optimally manipulated for best results. Hence, the production of cassava-wheat semolina noodles would be an added dimension in realizing the industrial potential of cassava, with a view to expanding its utilization, production and, in effect, improving the income of cassava farmers and marketers. Moreover, the availability of cassava based noodle products will ensure reduction in annual import bills on durum wheat based pastas.

This research project, in which a novel noodle product is being developed, is in line with Federal Government policy on import substitution, export promotion and economy diversification from crude oil; thereby making this a worthwhile venture.

1.1 Objectives

The specific objective of this research is to produce acceptable cassava-wheat semolina macaroni noodles that are comparable to wheat-based ones in quality, taste and appearance.

The general objectives are to:

i. Evaluate the chemical, physical, and physicochemical properties of 0, 20, 30, 50, 70 and 100% cassava-durum wheat semolina flour blends for noodles production.

ii. Determine the effect of cassava starch and hydration levels on cooking and sensory properties of macaroni noodles.

CHAPTER TWO

LITERATURE REVIEW

2.1 History and Origin of Noodles/Pastas

2.1.1 Origin of noodles/pastas

The terms ‘Pastas’ and “Noodles” are often used synonymously though it is believed that the former, usually refers to Italian style extruded products such as Spaghetti, and Macaroni which are made from durum wheat semolina (very hard and vitreous wheat). Noodles on the other hand are made from soft wheat flour by a process of sheeting and extrusion as desired. (Sowbhagya and Zakiuddin, 2001). Italy is regarded as the home of pasta products, though there are contrary views that they learnt it from the Germans (Donnelly, 1991), who in turn learnt it during their Asian travels.

Feillet *et al* (1996) when reviewing the past and future trends of pastas, noted that of all the academic researches being conducted, about 15% had been centered on the art of pasta production itself, while the processes of obtaining its basic raw material, semolina, had not attracted much attention (only 5% of total publication). However, by the 15th and 16th centuries, commercial production of pastas was developed in Italy, more so as their prevailing climate favoured the drying process of pastas (Sowbhagya and Zakiuddin, 2001). From Italy, pasta production spread rapidly to France, other European countries and to America.

2.1.2 History of noodles/pastas

Commercial production of pasta products dates back to the 15th and 16th centuries in Italy (Naples) where a favourable drying climate prevails. The first commercial production in USA was in 1848 in Brooklyn New York (Donnelly, 1991) and in this 21st century, pasta consumption has spread worldwide, even to Africa and particularly to Nigeria.

The Asian style noodles originated in Northern China, where wheaten foods have been popularly known (Miskelly, 1993). The art of making noodles dates back to 206 BC/220AD, and this spread from China to Korea, Japan, the Philippines, Thailand, Malaysia, Indonesia, Singapore, Burma and Vietnam (Nagao, 1981). Chinese traders, seafarers and those migrating to other countries initiated this spread. By the 17th century, some Asian countries were introducing local and native ingredients into noodle recipe, making it a part of the unique cuisines of these countries.

2.1.3 Development and production of noodle/pasta products

A wide variety of noodle products have been made throughout the world. The art of making noodles from wheat was well developed during the Han dynasty, between 206 BC and 220 AD. Noodles spread from China to Korea, Japan, The Philippines, Thailand, Malaysia, Indonesia, Singapore, Burma and Vietnam through Chinese traders, seafarers and migrants (Sowbhagya and Zakiddin, 2001). Pasta/noodle preparation basically involves mixing durum wheat semolina with 30%water preferably under vacuum and extruding the dough through a brass die with Teflon inserts (Sowbhagya and Zakiuddin, 2001). Pasta is thereafter dried at 70-90 ^{o}C to a moisture level of 11-13%. Noodles were soon adopted and blended with local/native ingredients as part of unique cuisines of these countries. Noodles were being made from rice flour, buck-wheat flour, mung bean starch, corn starch, potato starch etc. Processing methods were dependent on the presence or absence of ‘gluten’. Water was added as a processing aid in the extrusion step and is later removed by drying.

However, when cereals like rice and isolated starches are used, gelatinization during processing is often required to serve as a binder (Juliano and Sakurai, 1985). Starch-based noodles are thus made by mixing the starch with boiling water, kneading/mixing to smoothness; while the gelatinized starch act as a binder (Juliano and Sakurai, 1985). The resulting dough (if gluten is present), is sheeted and rolled and cut, or the batter (if gluten is absent) is cooked and extruded (Sowbhagya and Zakiuddin, 2001). Mung bean starch was used in the preparation of noodles by mixing treated mung bean starch with gelatinized starch and water; and the dough was passed through a sieve under pressure, followed by extruding the noodles into boiling water where they were cooked. These were then drained and frozen for 24 hours, defrosted and dried in the sun or air before packaging (Sowbhagya and Zakiuddin, 2001). Flour-based Asian noodles on the other hand are simply made essentially from a mixture of flour, salt or alkaline salt, and water. Other ingredients may be eggs, preservatives, colouring agents and gums. The basic process flow chart is shown in Figure 2.1.

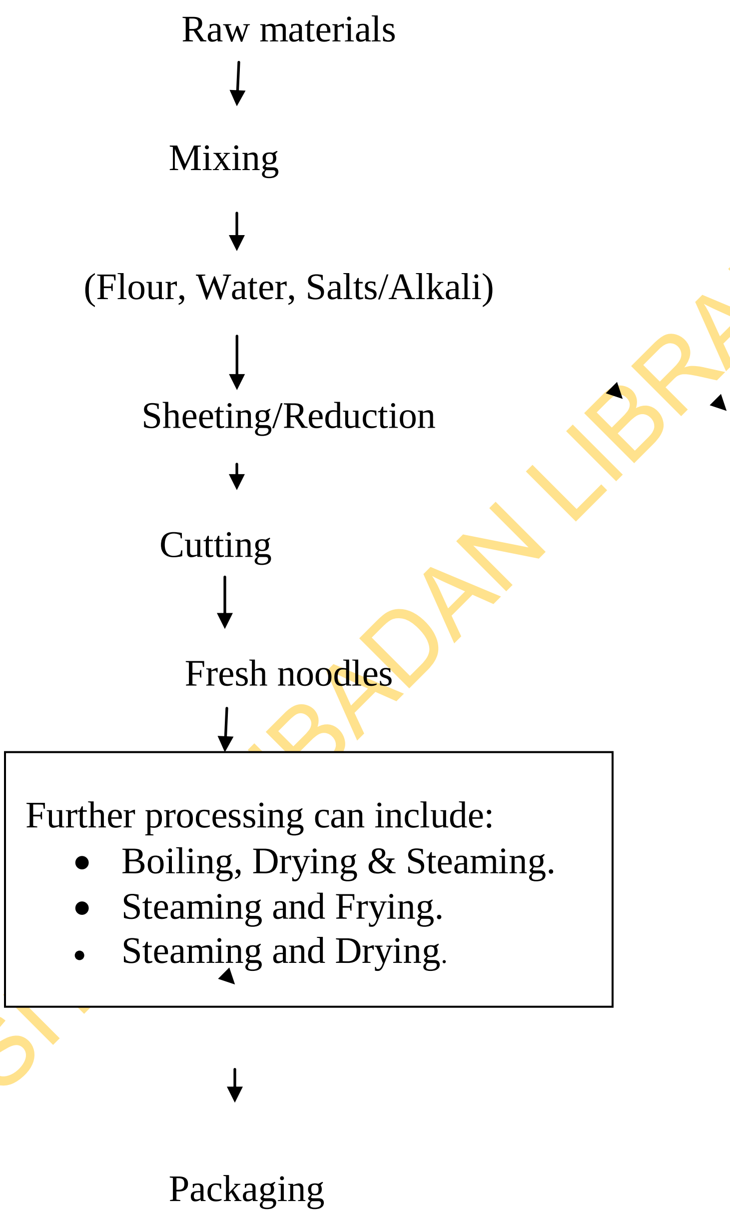

Figure 2.1 Flow chart for the production of Asian wheat flour noodles
Miskelly (1993)

Rice vermicelli was prepared by using a commercial production method in which wet-milled rice at 37% moisture was molded into an annular cylinder (Yoenyongbudhagal and Noomhorm, 2002). The surface of cylinder was then gelatinized by placing it in a conventional steamer for 15 minutes. Sample was then further premixed by extruding through a single-screw extruder with die opening 1 cm in diameter. Premixed dough was thereafter extruded through a fabricated single-screw extruder with die opening 0.5 mm in diameter. Extruded vermicelli was then steamed for 2 hours to become totally gelatinized, rested for 12 hours at ambient temperature, and dried in an air oven at 40 ^{o}C for 16 hours (Yoenyongbudhagal and Noomhorm, 2002).

2 .2 Types and Nomenclature of Noodle Products

Noodle products are usually named depending on the chosen basis of nomenclature. For instance, when based on country; it is broadly named European (type) or Asian (type) noodles; it could be further specified to be Chinese, Japanese, Italian, and German noodles, etc. Each of these countries/continents has their usually preferred specific method of production and raw material(s) (Sowbhagya and Zakiuddin, 2001). Noodles could be named along the principal ingredient used in its preparation such as rice, potato, mung-bean starch, sweet potato, taro, buck-wheat or cassava noodle (Kim and Wiesenborn, 1996). Shape of noodles is another point of reference; macaroni (elbow, big or small diameter), spaghetti (long rods), vermicelli (short rods), lasagna (flat sheets) and ravioli (ribbon shaped) (Kim, 1996). Noodle packaging method could also be used as a term of reference such as bag type and cup noodles (Huang, 1996; Kim, 1996).
The extent of cooking required can also be used as reference; raw or dried (uncooked), semi-instant (precooked or steamed), instant (steamed and fried) noodles. Another basis of reference could be the preparation method; i.e. Handmade (swung or sheeted, fresh), machine made (dried or fresh) noodles. Plate 2.1 shows a variety of raw and cooked noodle products.

Plate 2.1 Variety of raw and cooked noodle products.

2.3 Raw Material Requirements

2.3.1 Wheat based

Through the ages, the basic raw material traditionally used for the manufacture of noodle pasta products has been wheat (Kim, 1996). The Europeans preferably use durum wheat, *Triticum turgidum L. var. durum*, while the Asians use *Triticum aestivum*, commonly referred to as bread wheat (Sowbhagya and Zakiuddin, 2001). The endosperm of the former has the hardest texture of all wheat and its kernels are larger and more vitreous than those of the latter (Boyaciogiu and D'Appolonia, 1994). Durum wheat is an important crop used for the production of pasta, couscous and various types of bread products (Quaglia, 1988). Many researches have been carried out on the seed endosperm components affecting pasta quality, especially in terms of dough rheology, physiology, biochemistry and processing technology (Dick, 1985; Dick and Matsuo, 1988; Cubadda, 1989). Durum endosperm contains about twice the concentration of xanthophylls or lutein pigments compared to that of bread wheat. Unlike the latter, they are grown solely for other food products, apart from bread which include pastas i.e. spaghetti, lasagna, elbow macaroni, regional foods like couscous, bulgur, puffed or hot cereals and also flat and leavened breads (Dick and Matsuo, 1988). In countries such as Syria, Lebanon, Jordan and Egypt, durum flour is widely used alone or blended with other flours to produce flat breads and other pasta products (William *et al*., 1988; Liu *et al*., 1996). The quality of flour traditionally used for pasta making can be assessed for nutritional and/or processing purposes. According to Ding and Zheng (1991), quality standard for the flour required for noodle production includes gluten content (26-28%), farinograph stability (3-4 min.), falling number (> 200 sec.) and ash content (< 0.55%). Also, Huang (1996), while considering noodles made in China, listed four different types of wheat flour i.e.

a) common flour (having extraction rate of 85%, maximum ash content of 1.40% and minimum wet gluten content of 22.0%)

b)

flour (milled to an extraction rate of 81%, maximum ash of 1.1% and minimum wet gluten of 24.0%),

c) special flour[1] (having extraction rate of 70%, maximum ash content of 0.70% and minimum wet gluten content of 26%) and

d) special flour [2] (with extraction rate of 75% maximum ash content of 0.85% and minimum wet gluten content of 25%).

Reports obtained by Huang (1996) further indicated that noodles made with special flour [1] i.e. first class white flour was considered to be of best quality though its supply is restricted to special occasions. However, a formulated standard for noodle flours commonly adopted in China require: ash contents ranging from 0.55 to 0.70%; wet gluten, 26 to 28% and farinograph stability, between 3.0 and 4.0 min respectively for 1st and 2nd grades flour. For both grades, falling number 1CC – 107 should not be less than 200 seconds (Ding and Zheng, 1991).

Flour processes and pasta qualities can be determined with dough rheology or predicted by rheological tests using farinograph or alveograph (Liu *et al*., 1996). They could otherwise be empirically predicted by objective experiments (D'Egido *et al*., 1993). Milatovic and Mondelli (1991) pointed out that wheat flour with an alveograph P/L value of 0.8-2.0 generally produced a reasonable pasta or bread product, (although it is universally accepted that bread making require strong and extensible gluten) the strength requirement for pasta making is less clearly defined. It appears from literature that good pasta making quality requires only the dough strength as measured by the glutens' elastic recovery (R) of the visco-elastograph (Damidaux *et al*, 1978). Nonetheless, medium gluten strength is required for optimal pasta making quality (Matsuo and Irvine, 1970, Dexter *et al*., 1994).

The two basic ingredients for pasta making are flour and water. Quality pasta is made from semolina which is produced from 100% durum wheat. This wheat is especially bred and grown for pasta product worldwide. The protein of durum wheat is mainly responsible for the cooking quality of pasta products. High protein content and'strong' gluten is required to process semolina into a suitable final pasta product (Dexter *et al*., 1994). Water is an indispensable component of dough and baked products. The amount and state of water in wheat doughs, as in any dough, play an important role both in the preparation and in the final product. It is essentially added to flour during mixing (a hydration process). Hydration is necessary for gluten development, and for many interactions and chemical reactions that occur during mixing and baking (Ruan *et al*., 1999). The addition of water to flour causes hydration of the gliadin and glutenin proteins and leads to the formation of gluten. When flour is mixed with water, the gluten swells to form a continuous network of fine strands. This network forms the structure of bread dough and makes it elastic and extensible. Essentially, the stress induced by mixing breaks bonds between protein chains, allowing the chains to move and become realigned. The new bonds that are formed allow relaxation of the dough. Gluten strengthening (or oxidising) agents, such as, ascorbic acid stimulate the formation of these new bonds, strengthening the dough structure.

Protein quality was found to be of equal or even of more importance to noodle quality, than protein content (Huang, 1996). A measure of protein quality through the sodium dodecyl sulfate (SDS) sedimentation test was found useful in predicting noodle firmness and chewiness (Huang and Morrision, 1988). Research findings indicated that noodle flours with protein content between 9.5 and 11.0% and medium gluten strength would yield good quality noodles (Huang and Morrision, 1988; Huang, 1996).

2.3.2 Use of composite flour and starch

The use of blends of wheat and non-wheat flours, known as composite flour became popular in Nigeria when wheat was limited in supply (Okaka and Isieh, 1990). The composite flour concept could be examined in two ways, first, as a combination of wheat flour and one or more non-wheat flours; and secondly, as a wholly non-wheat flour prepared from one or more non-wheat crops (Dendy, 1992).

Investigations into the use of non-wheat flours have been of paramount importance, especially in the field of bread baking. This dated back to ancient times when bread and bread like products were made from flours of cereals (e.g. maize, sorghum, rice and millet), roots and tubers (e.g. cassava, yam, coco-yam and potato), legumes and oil seed (e.g. melon, soybean, groundnut and bean seeds). This was first seen as an emergency measure in industrialized countries during the two world wars of 1914 and 1945 when wheat supplies were limited (Dendy, 1992). Subsequently, ‘composite flours’ became the focus of attention in European and International cereal research in the 1960s and 1970s. In these two decades, bread consumption increased continuously in many of the developing countries. Two main reasons identified were, a steadily growing population and changes in eating habits. Developing countries have since then been interested in replacing the wheat needed for making bakery products and by extension, also pasta, wholly or partly with flours obtained from home-grown crops. Possible sources were tuberous plants rich in starch such as cassava, yam, sweet potatoes, protein-rich flours such as soy and peanuts, and other cereals including maize rice, millet and sorghum. Although, Seibel (1996) opined that no other crop can achieve the baking properties of wheat, several research efforts indicate certain success in the field of pastamaking (Faure, 1992; Sowbhagya and Zakiuddin, 2001; Yoengongbuddhagal and Noomhorm, 2002; Oladunmoye *et al.*, 2004). Nonetheless, pasta/noodle products like spaghetti and macaroni are often made not from ordinary wheat grain (*Triticum aestivum*), commonly referred to as bread wheat (Sowbhagya and Zakiuddin, 2001) or common wheat, but from hard vitreous wheat grain (*Triticum turgidum L. var. durum*), called durum wheat (Srilakshmi, 2001). Semolina is a coarse-ground flour fraction obtained from the milling of wheat grain endosperm of durum wheat grain during milling. This is a special flour of high gluten content, and carotenoid pigment lutein, which gives the yellow color to the pasta (Haraldsson, 2010).

On this premise, the Food and Agriculture Organisation of the United Nations initiated an investigation into composite flour usage and established the composite flour programme. As reported by Dendy (1992) this step was to identify those non-wheat sources that could be used in developing countries to extend the usage of wheat flour in bread making and hence effect savings in foreign exchange by reducing wheat importation (NFTS, 2001). Similar effort is due to extend the use of wheat semolina for pasta making.

The use of other cereals for noodle making, such as sorghum and maize (Faure, 1992), millet and rice (Sowbhagya and Zakiuddin, 2001; Yoengongbuddhagal and Noomhorm, 2002) have been reported with and without wheat incorporation. Reports indicate that in China, some noodles are made solely from rice. Also, non conventional raw materials such as mung-bean starch, Irish and sweet potato starches, taro corms and cassava flour have been tried for noodle making (Edwardson and Mac Cormac 1984; Lan and Ilagantileke, 1992; Collado and Corke, 1996; Kim *et al*., 1996; Kim and Weissenborn, 1996; Sowbhagya and Zakiuddin, 2001).

The potential for the industrial utilization of root and tuber crops is the focus of increasing interest in many parts of Africa (Scott *et al*., 1992) due to the fact that they may play a vital role in food security in developing countries, and are responsible for supplying the dietary energy needs of about 700 million people (Oyewole, 2002). The major root and tuber crops in Africa include cassava (Manihot species), yam (*Dioscorea spp*), cocoyam (*Colocasia spp*), sweet potato (*Ipomea batatas* (L)), and Irish potato. Root and tuber crops thrive in many parts of Africa (i.e. Nigeria, Ghana, Tanzania, Zaire, Uganda, Cameroon, Cote D'Ivoire and others), because of their agronomical advantages and low input requirements for cultivation (Scott *et al*., 1992; Oyewole, 2002). Of these root and tuber crops, cassava has been singled out and earmarked as an important food crop for some 500 million people in the Third World (De Bruijn and Fresco, 1989). Cassava plays a major role in meeting the energy need of over 40% of the sub-Saharan population (Onabolu, 1988). Hahn and Keyser (1985) while reporting on the food crises in many war torn and drought ravaged parts of Africa; noted cassava as the major food crop available to assist the dwindling populace. Cassava is highly rated as a famine relief crop in more than thirty-nine African countries (Haggblade and Zulu, 2003).

Production of cassava roots in Nigeria far exceeds that of all other major crops combined (Scott *et al.*, 2002). Cassava is also a major crop in Tanzania and Uganda (Nweke *et al.*, 2004), though the lack of variety of cassava products in the former discourages its greater consumption. By substituting cassava flour for only 20% of the wheat in the country for biscuit manufacture, Tanzania saved about USD 1.2 million of foreign exchange annually (Falade and Akingbala, 2008).

2.4 History, botanical description of cassava

2.4.1 History

Cassava is one of the earliest crops to be domesticated and is widespread throughout the New World tropics. Cassava is a perennial, vegetatively propagated woody shrub that is grown throughout the lowland tropics. It belongs to the Euphorbiaceae family and is commonly referred to as Manioc, Tapioca or Yuca. Cassava was not viewed as a food plant until 1835, and in 1850, when it was transported from Brazil to Java, Singapore and Malaya. Cassava is thought to have originated from Mexico, Central America and North Eastern Brazil (Grace, 1977), but the Portuguese around the 16th century first introduced cassava into Africa (Nartey, 1978).

The diffusion of cassava into the interior is poorly documented and only reported by European explorers who penetrated central Africa in the 19th century. Unlike central Africa, the diffusion of cassava in West Africa was slow and most of the spread occurred in the 19th and 20th centuries. In the late 19th and 20th centuries, colonial administrators encouraged its diffusion and increased cultivation (Lebot, 2009). Since then, its cultivation in Africa has expanded constantly, especially in the drier savannah areas. Major cassava producing countries in Africa, Asia and America are listed in Table 2.1. Total production in Africa increased from 35,000,000 tons in 1965 to over 80,000,000 tons in 1995 at an annual growth rate of 2.9%, which was roughly the same as the population growth rate. The increases in production during the past two decades were due largely to its ability to survive after cultivation and the viability of its stem-cuttings (Lebot, 2009). Now, cassava is cultivated in all the tropical countries of the world, including some isolated and remote islands of the Pacific (Table 2.3) and viewed as an important starchy root crop. Cassava is often used to replace more demanding root crops such as yams, in humid zones (Lebot, 2009). The great adaptability of cassava to marginal areas and its flexible growth cycle facilitated expansion worldwide, especially where there is high population pressure. When land is scarce, food requirements per unit of cultivated areas rise and farmers shift to crops such as cassava with its higher output of energy per hectare (Scott *et. al*., 2000; FAO, 2007). The cassava root is long and tapered, with a firm homogeneous flesh encased in a detachable rind, about 1mm thick, rough and brown on the outside. Commercial varieties can be 5 to 10 cm in diameter at the top, and around 15 cm to 30 cm long. A woody cordon runs along the root's axis. The flesh can be chalk-white or yellowish. Cassava roots are very rich in starch and contain significant amounts of calcium (50 mg/100g), phosphorus (40 mg/100g) and vitamin C (25 mg/100g). However, they are poor in protein and other nutrients. In contrast, cassava

Table 2.1 Major cassava producing countries in the world, 2006.

Region	Country	Production (thousand t)	Area (thousand ha)	Average yield (t/ha)
Africa	Nigeria	45,721	3,810	12.0
	Congo (ex Zaire)	14,974	1,846	8.1
	Mozambique	11,458	1,105	10.4
	Ghana	9,638	790	12.2
	Angola	8,810	757	11.6
	Tanzania	6,500	670	9.7
	Uganda	4,926	379	13.0
	Benin	2,524	173	14.5
	Madagascar	2,359	389	6.1
	Cameroon	2,100	350	6.0
Asia	Thailand	22,584	1,071	21.1
	Indonesia	19,928	1,223	16.9
	Vietnam	7,714	475	16.2
	India	7,620	242	31.4
	China	4,318	266	16.2
	Cambodia	2,182	96	22.6
	Philippines	1,757	204	8.6
	Malaysia	375	38	9.9
	Sri Lanka	226	24	9.6
	Myanmar	207	16.5	12.5
America	Brazil	26,713	1,902	14.0
	Paraguay	4,800	300	16.0
	Colombia	2,000	180	11.1
	Peru	945	86	11.0
	Venezuela	489	41	11.7
	Cuba	450	80	5.6
	Bolivia	374	37	10.1
	Haiti	327	71	4.6
	Argentina	176	18	10.0
	Ecuador	100	23	4.4

Source: www.fao.org, 2007

leaves are a good source of protein and rich in the amino acid lysine, though deficient in methionine and possibly tryptophan (Hudson and Ogunsua, 1976).

2.4.2 Agronomy:

Adaptability of cassava to relatively marginal soils, erratic rainfall conditions, its high productivity per unit of land and labour, the certainty of obtaining some yield even under the most adverse conditions and the possibility of maintaining continuity of supply throughout the year, makes this root crop a basic component of the farming system in many parts of Africa (Bokanga and Djoussou, 1996). Cassava grows best in a rich well drained loamy soil with light or medium rainfall though it could thrive also in moister climate (Grace, 1977). It is not a soil depleting crop and ecologically, can grow well below latitude 10^{o}N where annual rainfall exceeds 1000 mm. Reports indicate that within such region, cassava occupies a pre-eminent position in the farming systems, with an aggregate contribution of about 50-75% of both total farm hectare and crop output (Ngoddy, 1989). Time of maturity of cassava depends on the variety, the soil fertility and amount of rainfall; and it ranges from 12/18 months to 2 years though some can be harvested at 6-7 months (Irvine, 1969). Cassava grows easily with good yield since it is little affected by disease and pests in comparison to other crops. It is valued as a cash crop and often described as a famine relief crop, grown basically for its edible portion and a staple food in many tropical countries.

However, cassava deteriorates very rapidly after harvest due to its high moisture content. It therefore requires immediate attention and processing into intermediate stable forms or products to extend the shelf life beyond 2 or 3 days (Oladunmoye *et al.*, 2004, FIIRO, 2006).

2.4.3 Botanical description

The genus, Manihot is from the family of Euphorbiaceae and comprises of over 200 species, of which the Manihot (species) is the most important from nutritional and economic point of view (Nartey, 1978). These include: *Manihot utilissima pohl, M.aipi pohl* and *M. dulcis* and *M. palmata* etc. Early literature on cassava described the genus with two edible species: *M. utilissima pohl* and *M. aipi pohl* which have high and low cyanogenic glycoside concentrations. Cassava is easy to cultivate, having no critical period of propagation and harvesting, hence not season-bound. It requires minimum attention during growth and can tolerate both extremes of acidic and basic pH (Nartey, 1978, O'Hair, 1995). It has the ability to withstand drought, pests and diseases common to most root crops. It can be grown in extremes of rainfall, but it does not tolerate flooding in moist areas (O' Hair, 1995). In drought areas, it loses its leaves to conserve moisture, producing new leaves when rain resumes. It does not also tolerate freezing conditions (O' Hair, 1995). Cassava is grown in Africa between latitude of 15^{o}North and 15^o South where annual rainfall expectation is 75mm (Nartey, 1978).

2.5 Cassava Production and availability for noodle development

2.5.1 Production

Cassava (Manihort Esculentus (Euphorbiacea)) is grown in all the states of the Federation with the current production level being about 45 million metric tons per annum; a figure expected to double by 2020. Nigeria is the leading cassava producer in the world, producing a third more than Brazil and almost double the production capacity of Thailand and Indonesia. Although it is the world leader in cassava production, 90% of the annual production in Nigeria is targeted for the domestic food market (Anonymous, 2011).

Cassava is one of the most productive root crops in terms of yield per hectare (FOS, 2000). Cultivation requirement for cassava is minimal, for it grows easily, records large yield in comparison to other crops and can be harvested throughout the year. Cassava is tolerant of low soil fertility and drought. It has the ability to recover from damages caused by pests and diseases. The roots can be left underground for long periods as a food reserve, thus serving as an insurance against famine. Cassava is well adapted to traditional mixed cropping agricultural systems and subsistence cultivation in which farmers seek to minimize the risk of total crop failure (Wenham, 1995).

The estimated global production of cassava in 1960 was 70 million tonnes/annum, and within 30years; this figure more than doubled to 150 million tonnes (FAO, 1994); of these, 43% was produced in Africa, 35% in Asia and 22% in Latin America. Available records indicate that in Africa, cassava production increased from 58,200,000 tons in 1985 to 64,100,000 tons in 1990, a growth rate of 2% per annum. In Nigeria the 1980's ban on wheat importation provided a stimulus to cassava production, which rose from 13,500,000 tons in 1985 to 19,000,000 tons in 1990 (Wenham, 1995).

2.5.2 Cassava Availability

At two conferences held in South Africa organized by New Partnership for Africa's Development (NEPAD), jointly sponsored by Initiative for Development and Equity on African Agriculture (IDEAA) and International Food Policy Research Institute (IFPRI) in August and November, 2003, it was strongly recommended that cassava be promoted as a poverty fighter across Africa, facilitated by a continental or Pan-Africa Cassava Initiative. This initiative was based on a transformation strategy that emphasizes markets, collective action, the private sector, research and extension.

Much is being invested on cassava production and much is being expected. But, given the hopes and aspirations of many Nigerians, ignited by the Nigerian President's Initiative for cassava, many futuristic scenarios for cassava production are being debated. Food and Agricultural Organisation (FAO) and IFPRI suggest a more conservative production target for cassava. Extrapolating from estimates for cassava production in Africa (Scott *et al*., 2000) and (FAO, 2004b), opined that Nigeria's production should be targeted at 40 million tonnes by 2005 and 60 million tonnes by 2020 (IITA, 2002). This target was met and surpassed even before 2005 (Table 2.2) and this is likewise expected in 2020. This expectation relates well to the mapping of a simple linear time trend on historical production levels, as presented in FAO Corporate document repository (2007) shown in Figure 2.2. Nigeria's immense potential for cassava production is further shown by the current production trend shown in Figure 2.3.

2.6 Cassava post - harvest control, storage and uses

Cassava undergoes postharvest physiological deterioration once the tubers are separated from the main plant. When harvested cassava tubers are damaged,

Table 2.2 Estimate of cassava production in Nigeria

Year	Production (metric Tonnes)
1990	19,043,000
1991	26,004,000
1992	29,148,000
1993	30,128,000
1994	31,005,000
1995	31,404,000
1996	32,950,000
1997	33,510,000
1998	34,092,000
1999	35,980,000
2000	36,795,000
2001	37,949,000
2002	39,410,000
2003	41,853,400

Source: CBN Annual Reports and Statistical Bulletin, 2003

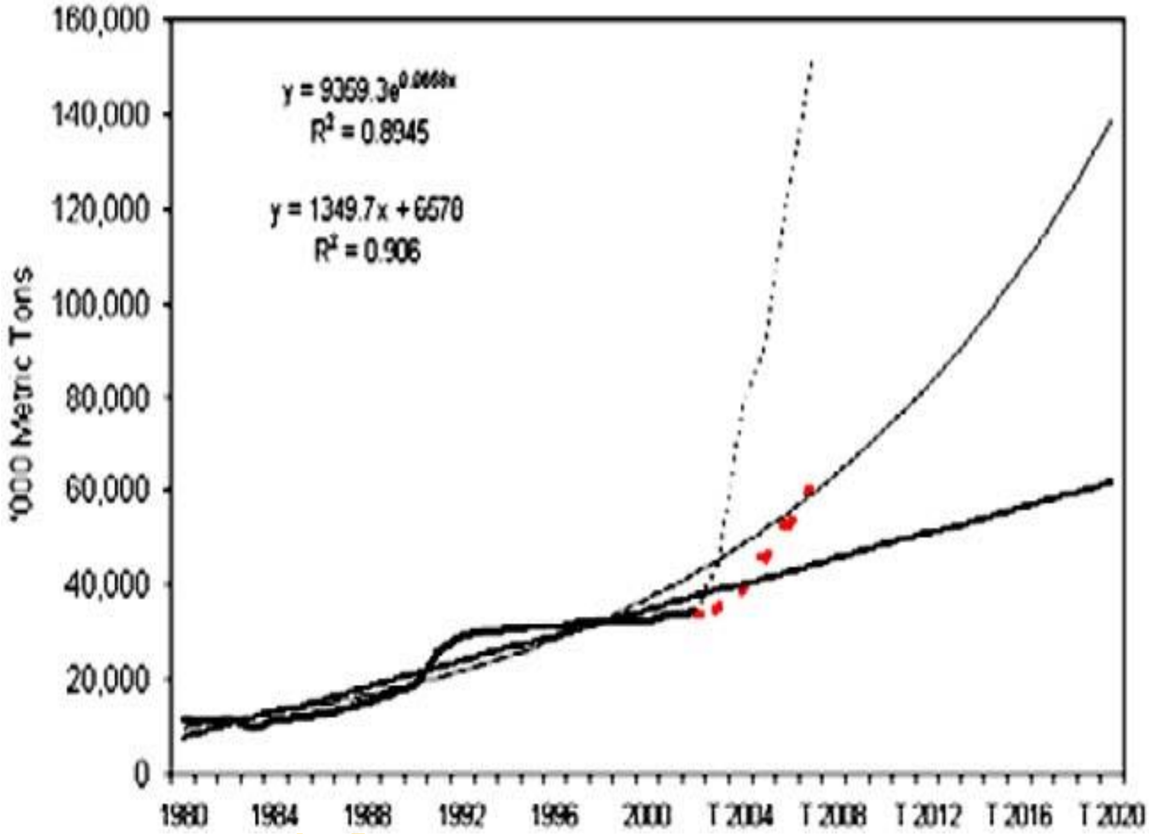

Figure 2.2. Production scenarios for cassava to 2020

Source: FAO (2005)

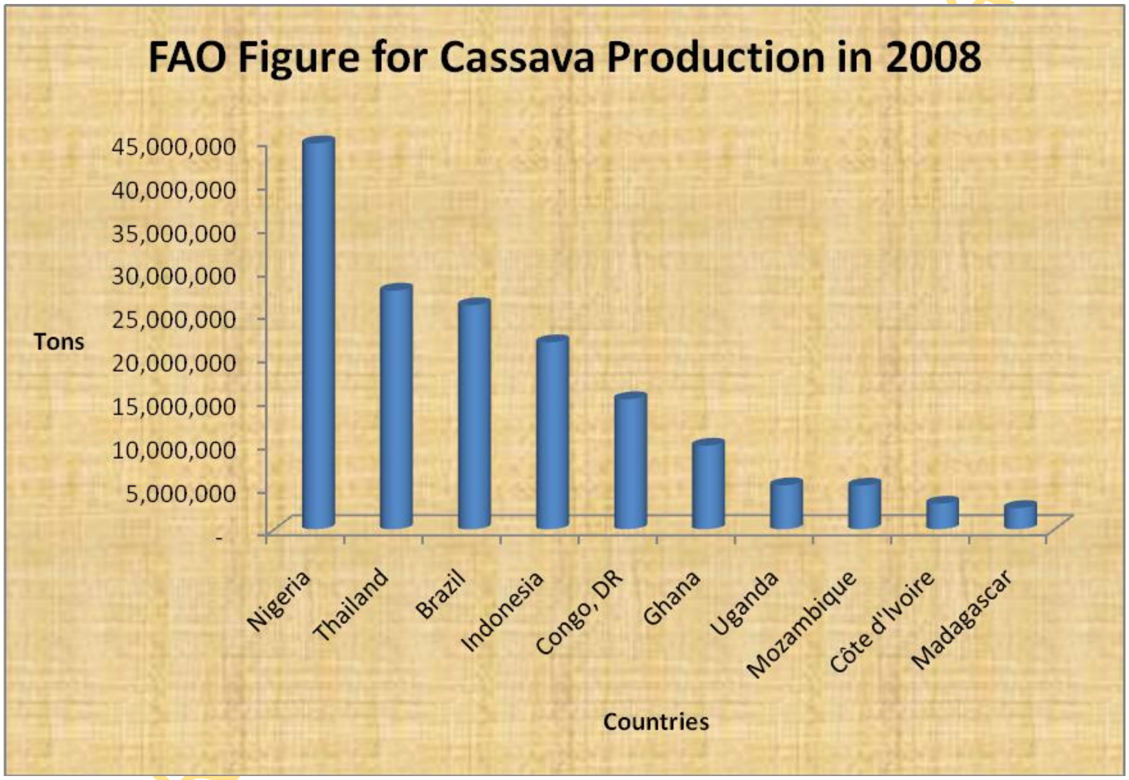

Figure 2.3 Production trend of cassava in 2008.
Source: FAO (2008)

deterioration, which is initiated within 15minutes, continues until the entire tuber is blackened within 2-3 days after harvest, thus reducing its quality and usefulness.

2.6.1 Post - harvest control and storage

Several attempts have been made to reduce or forestall production losses. Reeves (1985) in a training manual described six aspects of post harvest losses. These include: post harvest losses between maturity of crop and final consumption, food losses as to edibility and value; direct losses by diseases and pests; indirect losses by lowered quality leading to rejection or price slash; losses of crop product and post production losses. Some of these losses could be reduced or prevented in various ways, though only for a short period. For instance; cassava farmers traditionally keep the roots underground for several months (about 15 – 24 months) until they could be processed into flour or other stable forms (Irvine, 1969). However, roots kept in this manner have been reported to undergo lignifications and stand the chance of becoming tough, fibrous or woody. This reduces the quality, edibility and starch content of cassava roots and depending on the age, season and variety; it is sold at a discount, amounting to economic loss for both the farmer and the processor (Wenham, 1995).

Studies conducted by the International Centre for Tropical Agriculture (CIAT) and the Natural Resources Institute (NRI) resulted in the development of a simple storage system involving root curing in polythene bag and treatment with a thiabendazole chemical to prevent the onset of deterioration (Wheatley, 1989). This method of preservation has been successfully field – tested in many ecosystems in Colombia and the chemical residue in cassava tissues is reportedly less than 20% of the permitted level (Wenham, 1995). Direct loss of cassava roots on the farm occurs due to pests and diseases such as by mealy bugs, which feed on the leaves and stems of cassava, causing distortion to plant growth and reducing yield. *Prostephamus truncates* is now one of the major pests causing economically significant losses in cassava roots in Africa (Westby, 2002).

Damage is also caused by white flies that transmit cassava mosaic disease to the plant, thus resulting in loss of vigour and reduced crop yield. Apart from direct physical loss during harvesting, cassava roots senesce and deteriorates physiologically and pathologically immediately after harvest reducing shelf life to 24 – 28 hours. This rapid post - harvest deterioration may be associated with its lack of endogenous dormancy, having no function in propagation, and possessing no bud primordial from which re-growth can occur (Coursey and Booth, 1977; Passam and Noon, 1977). The high perishability can also be ascribed to the moisture content of fresh cassava roots, ranging from 80-92% (Ngoddy, 1989); or the enzymatic changes of rot and decay processes that eventually contribute to losses (Wenham, 1995, Grace, 1977) and often result in poor quality foodstuffs for urban consumers (Wheatley and Best 1991).

From recent studies (Lebot, 2009), cassava roots have been found to store at 3 ^{o}C, with 14% loss after 2 weeks and 23% after 4 weeks. If stored between 0 and 2 ^{o}C, an internal browning occurs. At temperatures above 4 ^{o}C, roots rapidly shows blue mold infections and are rejected after 2 weeks. Deep freezing in polyethylene bags also works, but the root deteriorates rapidly as soon as they are shifted to room temperature. A waxing treatment is currently used to extend shelf life especially for export purposes in the European Union (EU) and the United State of America (USA). Cassava roots are dipped in a 2.2% aqueous emulsion of fungicidal wax with 17% triethanolamine and 5% O-phenyl-phenol for 1 minute and then drained, dried and stored at room temperature (Lebot, 2009), with this treatment, only 10% loss is reported after 2-10 days. Roots dipped in ordinary paraffin wax, for 45 sec at 90-95 ^{o}C can be stored for 1 month. However, the best form of preservation is immediate processing into various shelf stable products either in the final or intermediate forms (Oladunmoye *et al.*, 2004; FIIRO, 2006).

2.6.2 Uses

All parts of the cassava crop are useful. The leaf is used to prepare vegetable soup and stews, also for meal wrappings by some tribes in Nigeria and Africa. The stem is used in the cultivation and propagation of the crop. The dried stem is also used as firewood. The roots are processed into primary and secondary products for food, domestic and industrial purposes.

Primary products of cassava are products directly obtained from cassava roots e.g. gari, fufu, starch, flour, chips and pellets. On the other hand, secondary products are those obtained from further processing of any of the primary products, or its by-products e.g ethanol, monosodium glutamate, glucose syrup, soy-gari, glues/adhesives, cold water starch, tapioca, cassava bread, cassava pasta, cookies/snacks, cassava based animal feeds, etc.(Oladunmoye *et al*., 2002; Anon, 2008).

The global usage of cassava has been increasing over the past 40-45 years. Its dominant use in Africa has been for human consumption as food, which has more than doubled between 1961 and 1995. In addition to its use as food, cassava is useful in compounding animal and livestock feeds, for making products for domestic market and for many industrial purposes. From collaborative study of cassava in Africa (COSCA), some prominent cassava food products are shown in Table 2.3. This shows that increased utilization of cassava in product development would add variety to consumables, more so that cassava has been used to alleviate food crises in many war-torn and drought-ravaged parts of Africa (Hahn and Keyser, 1985).

Cassava roots can be prepared and consumed fresh or-dried, processed into flour or starch with or without fermentation. A variety of products are thus obtained from both high and low cyanide cassava (Fig. 2.4). Though cassava has been reported to be nutritionally unbalanced, it serves as a basic energy source and when combined with a proteinous food item, makes a complete meal.

Garri, a dry granular meal, made from fermented cassava, is the most common form of consumption in West Africa. More than 70% of cassava produced in Nigeria is estimated to be processed into garri (FIIRO, 2006). Dorosh (1989) estimated that 40-50% of cassava produced in Cameroon is processed into garri, and same goes for 40% of Ghana production and 30% of Cote d'1voire production. In Nigeria, cassava is also sun dried into cassava flour (lafun) or fermented and processed into fufu, a sticky puree consumed with local soup (Scott and Suarez, 1992). Table 2.4 shows some common traditionally processed cassava products in some African countries (Hahn, 1986), while Table 2.5 highlights some properties of the major primary products of cassava that are of commercial importance (FIIRO, 2008). However, with the rapid spread of sweet type cultivars (i.e low cyanide varieties), cassava is now increasingly consumed, boiled directly after harvest in some parts of Africa (Table 2.6).

Cassava is also useful in the production of derived sugar products such as glucose, fructose, maltodextrins and mannitol, which have wide application in food, chemical and

Table 2.3 Type of cassava food product in Collaborative Study of Cassava in Africa (COSCA) countries

Country	Dried roots	Garri	Pastry product	Fresh roots	Others	Total
Congo	70	0	25	5	0	100
Cote D'Ivoire	8	45	8	37	2	100
Ghana	27	43	7	23	0	100
Nigeria	48	39	13	0	0	100
Tanzania	91	0	0	6	3	100
Uganda	21	0	0	76	3	100

Source: Nweke *et al.* (2002)

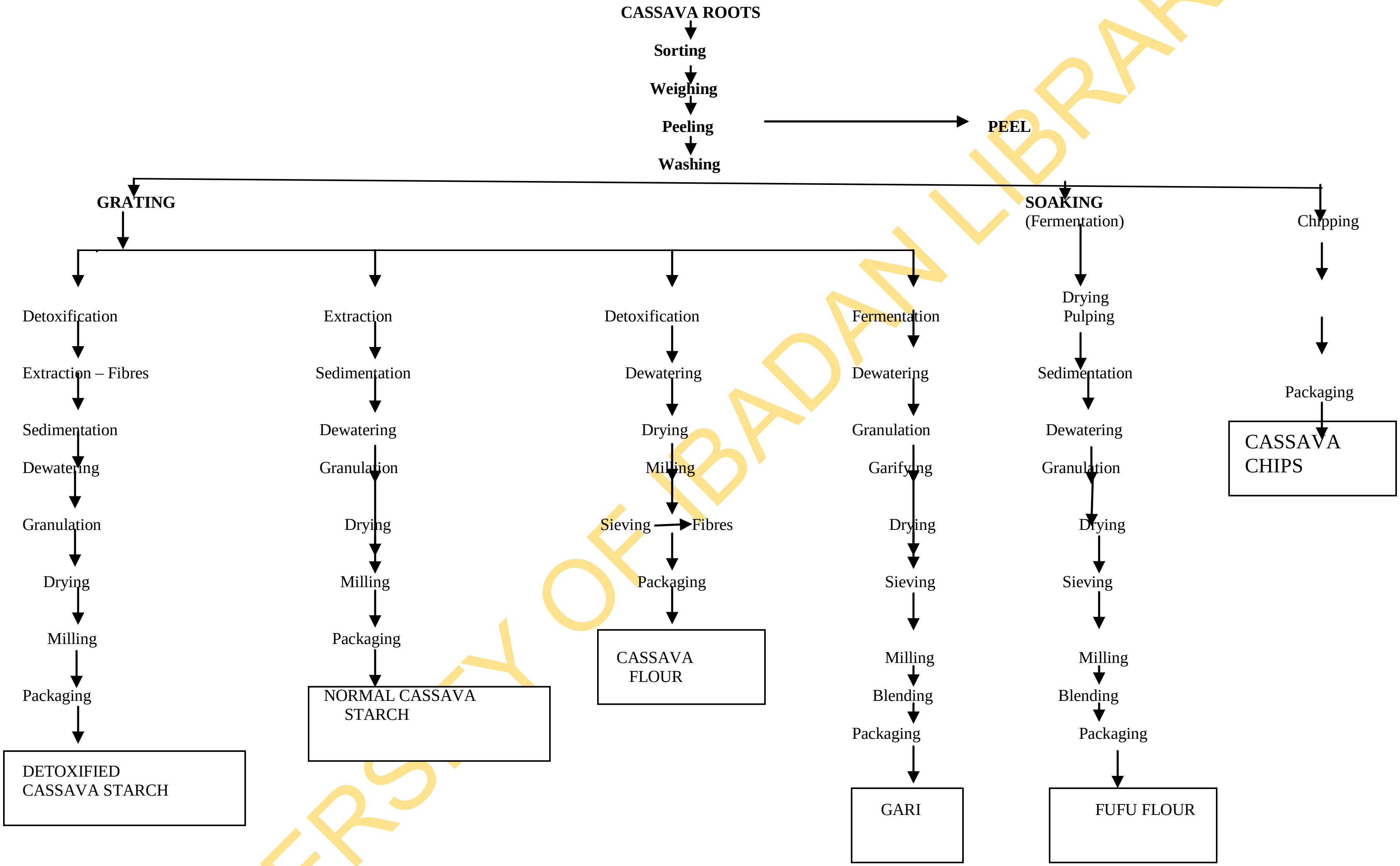

Figure 2.4 Industrial processing of cassava roots.

Table 2.4 Description of some cassava products

Product	Description
Chips	Pieces of peeled, sliced, dried tubers, which may be either plain or parboiled
Raspa de mandioca (Brazil	Cassava chips
Flour	Dry milled product from chips
Farinha de raspa (Brazil)	Cassava flour prepared from chips
Farinha de mandioca (Brazil	Cassava flour prepared by wet milling (maceration) of peeled roots followed by dry and milling/screening processes.
Pellets	Crushed ground chips and broken roots which are then compressed into pellets, sometimes with the addition of a binder.
Starch	Wet milled/screened refined product from root/tubers
Fecula (Brazil)	Starch
Tapioca (i.e grocery tapioca)	Flakes, pearls prepared by partial gelatinization of cassava starch
Tapioca spent pulp	Coarse dry powder, by-product of cassava starch extraction
Sago' (India)	Tapioca globules, pearls prepared from pure cassava starch as for grocery tapioca
Garri (West Africa)	Granular food product prepared from fermented, peeled and grated cassava roots.

Source: Tropical Products Institute Report (1978)

Table 2.5 Properties of some Primary Products of Commercial Importance from cassava

Property	Garri	Fufu	Starch	Flour
Colour	Creamy Yellow	Creamy white	White	White
Solubility in cold water	Soluble opaque	Soluble opaque	Insoluble transluscent	Soluble opaque
Moisture content	8 – 10%	8 – 10%	8 – 10%	8 – 10%
Cyanide content	Less than 10ppm	Less than 10ppm	Less than 10ppm	Less than 10ppm
Water Absorption	Very high	Very high	Very low	High
Gelling Power	Gels moderately	Gels moderately	Gels strongly	Gels moderately
Gel Elasticity	Non-elastic	Non-elastic	Very elastic	Fairly elastic
Taste	Slightly to strongly sour	Slightly sour	Tasteless	Mildly sour
Odour	Odourless	Odourless	Odourless	Odourless
Particle size range	0.4 – 1.5m	0.4 – 0.8mm	0.2 -0.3mm	0.2 – 0.3mm
Fibre content	About 5%	Less than 2%	Less than 0.1%	0.1 – 0.5%

Source: FIIRO Pilot Plant (2008)

Table 2.6 Simple house- hold processing techniques applied to low cyanide cassava roots

Country	Product	Processing Technique on fresh roots
West Africa	Fufu	Steaming or boiling peeled roots and pounding into sticky dough; eaten with soup
Nigeria	Gari	Roasted fermented granules
Ivory coast	Attieke	Steamed fermented granules
Ghana	Agbelima	Fermented cassava paste
Philippines	Landang (cassava rice)	Squeeze juice out. Pulp is made into pellets
Vanuatu	Laplap, a pudding	Grind roots into a paste, and steam-cook

Source: Lebot (2009)

pharmaceutical industries (Balagopalan *et al*., 1988; Rakshit and Patumthani, 2002). Additionally there are non-consumable products of cassava such as adhesives, monosodium glutamate, ethanol and others which are useful in paper, textile and oil drilling industries.

2.7 Cassava Toxicity and Control

Cassava roots contain free and bound cyanogenic glucosides; linamarin and lotaustralin. When the cells are ruptured, these are hydroloyzed and converted to poisonous hydrocyanic acid (HCN), in the presence of linamarase, a naturally occurring enzyme in cassava (Arguedas and Cooke, 1982). Cassava cultivars are more often classified according to the level of cyanide content in their roots, whether high (100 – 400 mg/kg) or low (<50-100 mg/kg) and are referred to as bitter or sweet cassava respectively (Hahn, 1986).

Low cyanide cassava roots could contain as low as 15 mg HCN/kg fresh weight (Coursey and Booth, 1977) and can be consumed raw as in some African countries, while it is boiled, steamed, or roasted in other parts of Africa (Table 2.12). On the other hand, the high cyanide varieties have to be processed or detoxified prior to consumption (Fig. 2.4). In Africa, especially in Ghana and Nigeria, cassava is traditionally fermented and processed into garri, lafun or fufu. It could also be sliced/diced and boiled as tapioca or ‘abacha’ (Ihekoronye and Ngoddy, 1989). Starch is also obtained through a process of grating, sieving and sedimentation. Figure 2.4 shows flow-chart of some cassava products whose processing involves a mixture of two or three or more of these unit operations; during which the roots become sequentially detoxified (FIIRO, 2008).

Linamarin, accounts for about 90% of the total cyanide content (Lebot, 2009), leaving the remaining portion as free cyanide. A large portion of this free cyanide occurs immediately below the peel and is often removed during peeling operation. However, during processing of cassava roots there is rapid conversion of bound cyanide to free cyanide (especially with root disintegration) which is then released into the processing water (FIIRO, 2006).

2.7.1 Cyanide control and detoxification measures

Naturally occurring free cyanide is very toxic and poisonous to man and domestic animals; hence it is not allowed beyond 30 ppm in foods (Aworh, 2010). On the other hand, cyanide not in bound glycoside form is a direct human poison. However, the digestive enzymes of man are capable of in vivo glycoside hydrolysis, thus releasing the toxic free HCN^- into the human system. Hence, both free and bound cyanide levels need to be monitored as a tool for predicting product wholesomeness. The National Agency for Food and Drug Administration and Control (NAFDAC) and Standards Organization of Nigeria (SON) have stipulated the safe permissible limit of cyanide in processed foods to be 10 ppm (SON, 1999).

The different process steps associated with cassava detoxification almost invariably involve one or more combination of size reduction, fermentation, de-watering, cooking and/or heat toasting (Aworh, 2010). The processing steps employed in the production of garri show how cyanide is sequentially being reduced or eliminated (Table 2.7). This schedule for eliminating cyanide is based on the fact that free cyanide is both water-soluble and heat volatile. The bound cyanide, on the other hand is first converted by enzyme or heat hydrolysis during processing, into free forms and thereafter, eliminated in soak water or wash water or cooking water; which is often discarded.

In a recent study, Dunfor (2007) reported the efficacy of cyanogens removal in traditional cassava processing techniques (Table 2.8) and shows that grating causes an extensive disintegration of tissues and hence contact between the enzyme (linamarase) and the cyanogenic glucoside (linamarin). As the inner peel is grated with the pulp, hydrolysis is activated because the enzyme activity is higher in the peel.

2.8 Characteristics and properties of starch

Starch is present in most plants and is used frequently as storage. Starch is the principal energy reserve in plants and is one of the most abundant carbohydrates in the biosphere. Starch is an excellent natural source of energy in human nutrition, being deposited in storage organs of starch crops such as corn, potato, cassava, wheat, etc. Starch occurs in starch granules and is of different shapes, depending on the source. Starch is versatile and has high potentials in various industrial applications, probably due

Table 2.7 Elimination of cyanide compounds during garri preparation

Unit operation	Effect
Peeling	Elimination of cyanogenic compounds with the peel
Grating	Linamarase brought into contact with Linamarin
Pressing & Fermentation	Inactivation of Linamarase stabilization of acetone cyanohydrin
Drying	Elimination of hydrocyanide and acetone cyanohydrin
Frying/heat toasting	Further elimination of cyanide acetone cyanohydrins by application of dry heat with or without palm oil

Source: Okaka (1977)

Table 2.8 Efficacy of six traditional processing techniques to remove cyanogens.

Food	Region	Processing steps*	Days	Cyanogens removed %
Casabe	America	Scrape, **grate**, wash, separate starch, ferment. drain, cook	3	97
Garri	West Africa	Peel, **grate**, ferment, drain, toast	4	93
Farinha d'agua	South America	Peel, soak, **grate**, ferment, drain, toast	8	99
Baton de manioc	Africa	Peel, chop, soak, drain, pound, wrap, **boil**	5	>99
Fermented flour	East Africa	Sun-dry, ferment, crush, **sun-dry**, pound, sieve	6	95
Sun-dried flour	Africa	Sun-dry, pound, sieve	17	66

Source: Dufour, 2007; * = Step during which majority of the cyanogens are removed is bold to its well-defined chemical properties (Blennow, 2004; Donald, 2004). Many starch properties depend on the particular source of starch, as well as on its previous treatment. The chains of starch are capable of an infinite variety of molecular conformations and interactions. These affect starch's physical nature and hence its performance in biological situations (Dexter, 1973). The amount and distribution of water within the starch granule is important with regard to the physical properties and chemical reactions of starch. Most of the water bound to starch is in the gel phase (at the surface of crystallites), about 70% of which is accessible as a solvent for D-glucose units. The remaining 30% is sterically inaccessible as a solvent (French, 1984). The starch granule is heterogenous both physically (having both crystalline and amorphous phases) and chemically (containing both amylose and amylopectin).

Starch is isolated primarily from cereals and root crops, especially on commercial scales. Cassava (or Tapioca) ranks very high among crops that convert the greatest amount of solar energy into soluble carbohydrates per unit of area. Among the starchy staples, cassava gives a carbohydrate production which is about 40% higher than rice and 25% more than maize, with the result that cassava is the cheapest source of calories for both human nutrition and animal feeding. A typical composition of the cassava root is moisture (70%), starch (24%), fiber (2%), protein (1%) and other substances including minerals (3%) (Tonukari, 2004). Compared to other crops, cassava excels under suboptimal conditions, offering the possibility of using marginal land to increase total agricultural production (Cock, 1982). Plant breeders, agronomists and molecular biologists have made substantial improvements in cassava yields during the past two decades, while, genetic characterization and mapping has revealed some insights into the molecular nature of cassava (Tonukari *et al*. 1997; Fregene *et al*., 2003). Some other cereals like sorghum, legumes such as, mungbean, are also good starch sources that have found specific applications in certain products (Abubakar, 2010) due to their physicochemical properties.

Starches occur in nature as granules and compose essentially of amylose and amylopectin fractions. The two polymers are very different structurally - amylose being linear and amylopectin highly branched. Amylose is predominantly of linear chains of alpha-1,4 linked glucose units while amylopectin is highly branched, with alpha-1,6 linkages between its glucose units (Eliasson, 2004). With the help of a microscope it is possible to determine the source of the starch, as the size and the shape of the starch granule differ for each kind of starch (Anonymous, 2012) (Fig. 2.5). Each polymer plays a critical role in the ultimate functionality of the native starch and its derivatives: viscosity, shear resistance, gelatinization, textures, solubility, tackiness, gel stability, cold swelling and retrogradation all depend on the amylose/amylopectin ratio (FAO, 1998).

Physical properties of starch are greatly influenced by its amylose content, for this has bearing on the swelling power and retrogradation tendency. Some reports (Oda *et al* 1980; Toyokawa *et al* 1989) have associated low amylose content of flour with good texture of white salted noodles. Sasaki *et al*. (2000) observed that the variation in amylose content was narrow within the same type of starch. Table 2.9 shows the granule size distribution of various starches and their amylose content. Amylose exhibit two main behavioral properties. It forms strong inclusion complexes (helical structure) with materials such as surfactants, iodine and lipids with much ease. Secondly, its molecules are able to form strong intermolecular interactions that lead to precipitation of the polymer as is the case with retrogradation (Abubakar, 2010; Delcour *et al*. 2010). Structural determination of amylopectin on the other hand, is difficult, due to the lack of recognition points. The alpha –D-1, 6 bonds give rise to infinity of possible arrangements, with its branch points occurring in clusters. The highly branched structure of amylopectin prevents regular conformations being formed in solution, thus retrogradation rarely occurs and binding by helix formation is inhibited.

2.8.1 Physicochemical properties of cassava starch

Root and tuber starches show considerable variation in their physicochemical properties such as granule shape and size, X-ray diffraction (XRD) patterns, amylose content and presence of non-starchy components. Factors like genetic origin, environmental conditions and age of the plant also influence the properties (Moorthy 2002). Baafi and Kantanka, (2007) likewise reported that the age of cassava roots on harvest and the location of cultivation influences the physicochemical and functional properties of its starch. Also, physicochemical properties of starches depend on the interaction of several factors including the internal organisation within their granules, the granule size, the amylose and amylopectin constituents, and other components such as

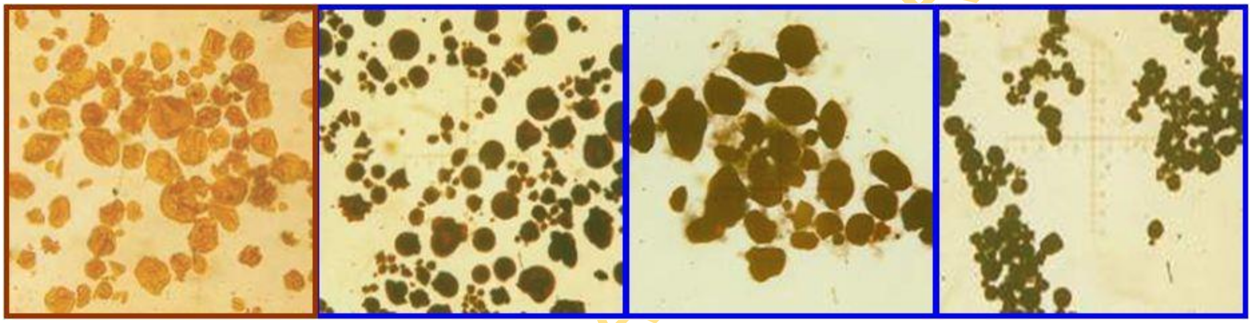

Figure 2.5: Starch granules (from left to right): waxy maize, tapioca, potato, maize

Source: Anonymous (2012)

Table 2.9 Granule size distribution of various starches and their amylose content

Starch Species	Granule Size Range (µm) (Coulter Counter)	Average size	%Amylose content in starch
Waxy Rice	2-13	5.5	0
High Amylose Corn	4-22	9.8	70
Corn	5-25	14.3	28
Cassava	3-28	14	17
Sorghum	3-27	16	0*
Wheat	3-34	6.5, 19.5	26
Sweet Potato	4-40	18.5	18
Arrowroot	9-40	23	21
Sago	15-50	33	26
Potato	10-70	36	20

Key: *=Waxy Sorghum
Source: Satin (2009)

lipids, moisture, nitrogen (protein), phosphorus and trace elements (minerals). The functional characteristics like viscosity, swelling power and solubility also depend on a number of factors such as varietal variation, method of extraction, processing conditions and instruments used for analysis (Hermansson and Svegmark, 1996).

2.8.1.1 Swelling power, Solubility and Water binding capacity

One of the important properties of starch is its ability to swell and leach soluble materials when heated above its gelatinization temperature and this determines its specific functional property when utilized in food products (Noranizan *et al.*, 2010). Swelling power is a measure of hydration capacity, because the determination is a weight measure of swollen starch granules and their occluded water. Starch granules swells slightly and reversibly in cold water to about 10-15% increase in diameter (Adejumo *et al.*, 2011), but with the application of heat, water is absorbed by the granules and swelling goes beyond this stage to an irreversible stage called gelatinization. At this stage, the individual starch granules swell, lose their birefringence, the crystalline structure is disrupted and water molecules become linked by hydrogen bonding to the exposed hydroxyl groups of amylose and amylopectin (Singh *et al.* 2003). Swelling continues as starch granules imbibe water, till a portion of the low molecular weight amylose dissolves and leach out into the surrounding aqueous medium, and forms a paste. Hoover (2001) explained that the swelling and solubility of starch is an evidence of the magnitude of the interaction between starch chains within the amorphous and crystalline domains. The extent of this interaction is influenced by the amylose-amylopectin constituents, their molecular weight distribution and the degree and length of branching. Nwokocha *et al.* (2009) studied the swelling power and solubility of cassava and cocoyam starches to understand the nature of their intra-granular bonds. He associated the low temperature relaxation (60 ^{o}C) and the rapid swelling of cassava starch at lower temperatures, to a weak intragranular organization compared to cocoyam starch, though their solubility were similar at 95 ^{o}C. However, reaction with water, or the water binding capacity is dependent not on the presence or absence of branching, but on the density and regularity of packing of the polysaccharide chains (Abubakar, 2010).

2.8.1.2 Gelatinization, pasting and retrogradation of cassava starch

The gelatinization temperature of starch depends upon plant type and the amount of water present, pH, types and concentration of salt, sugar, fat and protein in the recipe, as well as derivatisation technology used. Some type of unmodified native starches start swelling at 55 °C, other types at 85 °C. The gelatinization temperature depends on the degree of cross-linking of the amylopectin, and can be modified by genetic manipulation of starch synthase genes (Anonymous, 2012).

Starch granules have ordered semi-crystalline and birefringent structures. When starch is heated in excess water, as the temperature of the suspension is increased, the strong intermolecular bonds in the crystalline region are disrupted. Around a critical temperature range the starches undergo a reversible process known as gelatinization. Gelatinization is the process in which starch becomes soluble, binds water and forms a gel. *Gelatinisation* is characterised by crystalline melting, loss of birefringence and starch solubilisation (Fig. 2.6). Starch swells up by heating and continues to swell up absorbing water and showing more viscosity and clarity along with increase of temperature. At a certain point the maximum viscosity has been reached. Amylose leaches from the starch granule but amylopectin remain associated. With further heating, the starch molecules will move further apart and the viscosity is decreasing, the granules become distorted, soluble starch is released into the solution and eventually total disruption of the granule occurs resulting in a decrease in viscosity. Nwokocha *et al*. (2009) observed that cassava starch gelatinized at a lower temperature range (60.11^{o}–72.67 ^{o}C) compared with cocoyam (72.96^{o} – 80.25 ^{o}C). The wider gelatinization range of cassava starch relative to cocoyam starch indicates greater heterogeneity of crystallites within the cassava starch granule population (Gunaratne and Hoover, 2002). Gelatinization range has been reported to be dependent on difference in degree of heterogeneity of crystallites within the starch granules. Adejumo *et al.* (2011) listed how cassava starch progressively gelatinizes when heated in excess water. They showed that the granules (i) hydrate progressively, (ii) double helices undo as hydrogen bonds are ruptured, (iii) crystalline regions are converted to amorphous regions as a consequence of (ii), (iv) granules continue to imbibe water and swell and (v) ultimately the granules swell so much that granular form is lost and they tend towards gelation (~4% solids) and/or solubilisation (≤4% solids).

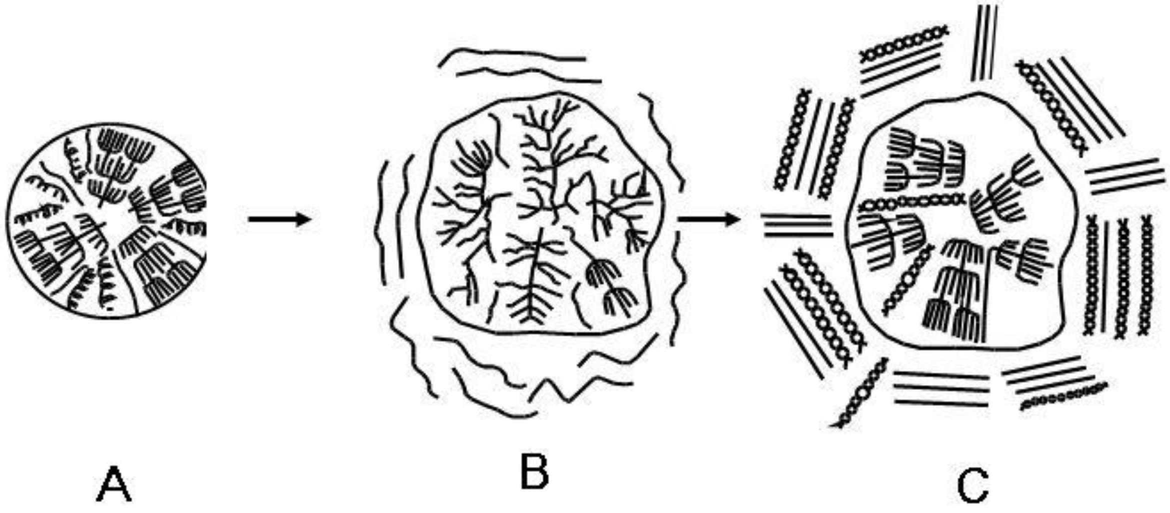

Figure 2.6: Gelatinization and retrogradation of starch.
A: Native starch, B: Gelatinized starch, C: Retrograded starch
Source: Anonymous (2012)

As soon as the temperature rises above the gelatinization temperature the starch granules begin to swell, when most of granules have become swollen, there is a rapid rise in viscosity if there is sufficient concentration of starch (about 10% w/v). As the temperature increases further, the granules rupture the more soluble amylose leaches out into solution followed in some cases by the amylopectin fraction. The granule rupture and subsequent polymer alignment due to mechanical shear reduces the apparent viscosity of the paste (Sissons, 2008). These combined processes that follows gelatinisation is called *pasting*. The pasting characteristics of starches has been correlated with cooking quality and texture of various food products (Moorthy, 1999), therefore it can be a good index of textural quality in most starchy food.

When the solution is cooled down viscosity is gradually increasing again and continuous cooling makes the solution cloudy (as is the case with wheat starch). On cooling a gel is formed, composed of swollen starch granules in an amylose matrix and the gel-strength is determined by the type and concentration of starch in the product. When a starch gel is left to stand for some time, the amylose molecules will lose water and bind together, gelatinized starch starts to re-associate in an ordered structure and retrogradation occurs. Many authors report that gelatinisation and retrogradation of starch from various botanical sources depend on the amylose:amylopectin ratio (Sasaki *et al.*, 2000; Donald, 2004). Gelatinisation process makes the starch not only useful as a thickening agent, but also renders it more easily digestible (Donald, 2004).

2.9 Functional properties of wheat semolina and flour used in noodle making

Few studies have been reported on noodle qualities and how it is affected by the flour components (Toyokawa, *et al.*, 1989). Majority of research attention on wheat and flour quality, have been in relation to breadmaking properties (Oh *et al.*, 1985; Toyokawa, *et al.*, 1989). Evidently, most reported studies apply to the quality of wheat flour for cakes, cookies and breadmaking, rather than for noodles. Oda *et al* (1980) also reported that the characteristics of starch are very important to the eating quality of noodles.

Durum flour is made from durum wheat. Durum wheat is not the same as common wheat, which is used in white and whole wheat flours for breadmaking. Durum wheat has a very hard kernel, and very high in protein (12–15 percent) content. It is also high in yellow carotenoid pigments, which provide a desirable golden color to pasta products. The two main constituents of durum wheat semolina are starch (78%) and proteins (13%), while its minor constituent include fibres, lipids, vitamins and minerals (Petitot *et al.*, 2010). Besides being used in pasta, durum flour is used in specialty baked goods, such as Italian semolina bread. Wheat kernel hardness deserves particular attention since it affects the tempering conditions, flour starch damage level, flour particle distribution and milling yield. Essentially, it is the starch and protein constituents of flour that governs the quality of noodle or pasta. Flour colour, particle size, swelling power, pasting properties, water absorption capacity, water binding capacity, starch damage properties, amylose/amylopectin ratio, α-amylase activity, dough mixing stability and gluten content.

2.9.1 Flour particle size distribution, starch damage and colour

Flour particle sizes and their distribution have been reported to influence the rate of hydration of the milled product during pasta processing (Dalbon *et al.*, 1996; Manthey and Schorno, 2002). Durum wheat semolina, as used in noodle and pasta producing companies, is coarse or granular to hand-feel and in appearance; while starch extracted from cassava tubers inadvertently has fine particle size distribution having gone through a process of maceration, pulping, milling and sieving. Petitot *et al*., (2010) reported an observed heterogeneous hydration of particles when semolina and legume flours of different particle size distribution were blended, resulting in formation of large dough lumps. Large particle flours require a longer time for water to incorporate and tend to form larger dough lumps. It is desirable to have relatively fine and evenly distributed particle size flours to achieve optimum dough mixing. Yet, granule size should not be too fine as it increases risks of starch damage which has a negative impact on the quality of the final product.

Starch in flour is damaged during milling and sometimes inherent in the wheat grain. Damaged starch in flour is important because enzymes in the flour, namely alpha- and beta-amylase, work on the damaged starch to produce compounds that are converted to simple sugars for feeding the yeast during fermentation and also to contribute to the residual sugars in the dough at the time of baking to promote better crust browning during bread baking. Increased starch damage results from reduction in flour particle size and it influences the likelihood of water linking with the starch or with the protein structure.

Starch damage influences so many aspects of dough including: dough hydration, handling (stickiness), fermentation and the final product characteristics (volume, colour, stability). This is more important in breadmaking, where adequate gassing is required during fermentation. Damaged starch not only absorbs more water but may also reduce noodle cooking and eating quality. Accordingly, noodle wheat should not be too hard, and milling processes should be controlled to avoid excess starch damage (Chiang *et al.*, 1973). High levels of damaged starch increase baking time, decrease water penetration inside the product, and cause higher loss of product during cooking. All these factors give the final product a sticky texture and a very bad mouth feel quality. Starch damage, when excessive, is also the cause of a browner product colour which is undesirable especially to bread consumers.

Durum wheat semolina is granular, reducing its particle size would increase starch damage and gassing power, but reduce dough stability (Saperstein *et al*., 2007). Grant *et al*. (1993) studied the effect of replacing semolina into the milling process to increase starch damage. They discovered that water absorption increases and dough firmness decreases with the increase of starch damage. The use of fine semolina can increase the amount of reducing sugars in the dough mixture allowing the action of endogenous alpha amylase to produce reducing sugars, which can eventually be converted to Maillard products (undesirable colour) during high temperature drying of pasta (Sensidoni *et al.*, 2003). Gauthier *et al*. (2006) associated semolina of too fine granulation (< 210 um) to increased cooking loss and reduced pasta firmness.

Flour color may be more related to noodle color. Colour of noodle flour should be preferably bright or golden yellow. This is usually dependent on the wheat milling extraction rates, the processing procedures and drying method for cassava flour/starch.

The colour scales most widely used in the food industry are the Hunter L, a, b and the CIE (Commission Internationale d'Eclairage) L*, a*, b* scales. These 3-dimensional scales are based on the opponent – colours theory that states that the red, green and blue human eye cone receptor signals are re-mixed into black-white, red-green, and yellow-blue opponent colours as the signals move from the eye up to the optic nerve to the brain. This imply that,

- L (lightness) axis -0 is black, 100 is white;
- a (red-green) axis- positive values are red; negative values are green and 0 is neutral; and
- b (yellow-blue) axis- positive values are yellow; negative values are blue and 0 is neutral.

All colours that can be perceived by the human eye can be expressed in terms of this colour scale. The colour difference between a sample and a standard can be determined using these colour scales, calculated as SAMPLE minus STANDARD, denoted as Δ

When Δ L is positive, then the sample is lighter, and when negative, sample is darker.

When Δ a is positive, then the sample is more red, and when negative, sample is more green.

When Δ b is positive, then the sample is more yellow, and when negative, sample is more blue.

Flour color L * >90 (measured with a Minolta Chroma Meter) is often required. Flour colour is affected by the lipid constituent of wheat semolina. Lipids are important components of wheat (1-3%) and they contribute to the colour of pasta due to the pigments contained in the wheat endosperm. Incomplete hydration of flour also affects the appearance, mechanical strength and cooking quality of noodles (Manthey and Schorno, 2002).

2.9.2 Protein, amylose, ash and pasting properties

Flour amylose content between 22-24% is often required for Japanese type noodle making. Flour protein, ash content and flour-pasting characteristics are major specifications for noodle and pasta making.

Protein content varies according to the noodle type to achieve the desired eating quality. Wheat protein (gluten), along with starch constituent is responsible for much of the structure-building properties of flour. Gluten is formed from two proteins in flour, glutenin and gliadin, when flour is mixed with water. Protein quality can be characterized by a range of tests to indicate gluten viscosity and elasticity. Gluten proteins provide the means for a gas holding, structure forming network. Gluten elasticity is essentially important for breadmaking, as the gas formed during fermentation (carbon-dioxide) need to be trapped within the gluten matrix, to give the characteristic bread structure and shape. Dubat (2004) reported that the volume of bread can be improved providing that the retention of fermentation gas is controlled. If not, dough becomes porous and can lose volume while inside the oven. Similarly, weak and inelastic gluten would result into poor pasta cooking quality, though the optimal gluten strength required is unknown (Sissons, 2008). Millers often blend flour of weak gluten strength with higher strength semolina so as to enhance pasta texture (Marchylo *et al.*, 2004). Oh *et al* (1983) found that the protein content of flour influenced the chewiness of cooked noodles. Attempts have been made to produce gluten-free bread (Frederick, 2007). Different technologies have been tried to make up for the lack of a protein network that could hold the produced gas and create the usual bread structure. Several methods of doing so were mentioned, including the use of various ingredients that assist in creating cohesiveness and holding particles together. Hoseney (1994) noted that for wheat, finer flour particle size—with the optimum absorption—can create more cohesion in most baking systems.

However, for pasta making, there is neither fermentation nor gas produced for trapping. The desired cohesiveness is only needed for good cooking qualities. Unfortunately, research on the effects of cassava starch particle size on gluten-free pasta or noodle systems appears to be scanty or non-existent. As a result, studies on the effect of wheat flour particle size are being utilized to make inferences and hypotheses as to how cassava starch may perform in pasta production. Generally, flour protein content has a positive correlation with noodle hardness and a negative correlation with noodle brightness. Thus, there is an optimum flour protein content required for each noodle type. Japanese udon noodles require soft wheat flour of 8.0-9.5% protein. Other noodles require hard wheat flours of high protein content (10.5-13.0%), giving a firmer bite and springy texture.

Flour ash content has been rated as one of the important specifications because it affects noodle color negatively. Flour ash content is largely determined by the wheat's ash content. Low ash content in flour is always an advantage for noodles since flour ash is traditionally viewed as causing noodle discoloration. Wheat with an ash content of

1.4% or less is always an advantage. Most noodle flours require ash content below 0.5%, but premium quality noodles are often made from flours of 0.4% or less ash.

Starch pasting characteristics (as measured on the amylograph or Rapid Visco Analyzer) also play an important role. The different parameters that can be deduced from RVA curves are shown in Figure 2.7. The ratio of amylose to amylopectin content determines a starch's pasting characteristics. Measurement of the pasting viscosity of flour relates to noodle quality, and eliminates a starch isolation step. However, the presence of excessive alpha-amylase activity (breaks down starch) in the flour will undermine the prediction results because a small quantity of the enzyme will likely reduce the paste viscosity. Many manufacturers opine that even moderate levels of sprout damage are detrimental to pasta cooking quality. Falling number is the term used by millers and bakers to refer to alpha amylase activity.

Dough properties measured by other relevant tests (sedimentation test, and **farinograph** and extensigraph measurements) are often also included in noodle flour specifications because they affect noodle processing behaviour and noodle eating quality.

Extensigraph parameters measure the balance of dough extensibility versus elasticity. Too much extensibility results in droopy dough, while too much elasticity causes difficulty in controlling final noodle thickness. Farinograph stability time has shown a positive relationship with Chinese raw noodle texture and tolerance in hot soup. It should be cautioned that noodle dough is much lower in **water absorption** than bread dough (28-36% versus 58-64%). Rheological tests, initially developed to evaluate bread dough performance, may not be applicable to noodle dough evaluation. Dubat (2004), after studying many aspects of noodle and pasta flour characteristics, observed that there is a need to develop new tests specifically for relating noodle dough's rheological properties to eating quality.

2.9.3 Alpha-amylase, α-amylase activity, falling number

Alpha-amylase is a starch-degrading enzyme. It splits the straight chains of starch (more precisely those of amylose and amylopectin) into smaller molecules (dextrins). It also enhances browning. The enzyme develops when grain sprouts. It has a direct impact on bread quality and adversely affects the malting process. The alpha-amylase breaks

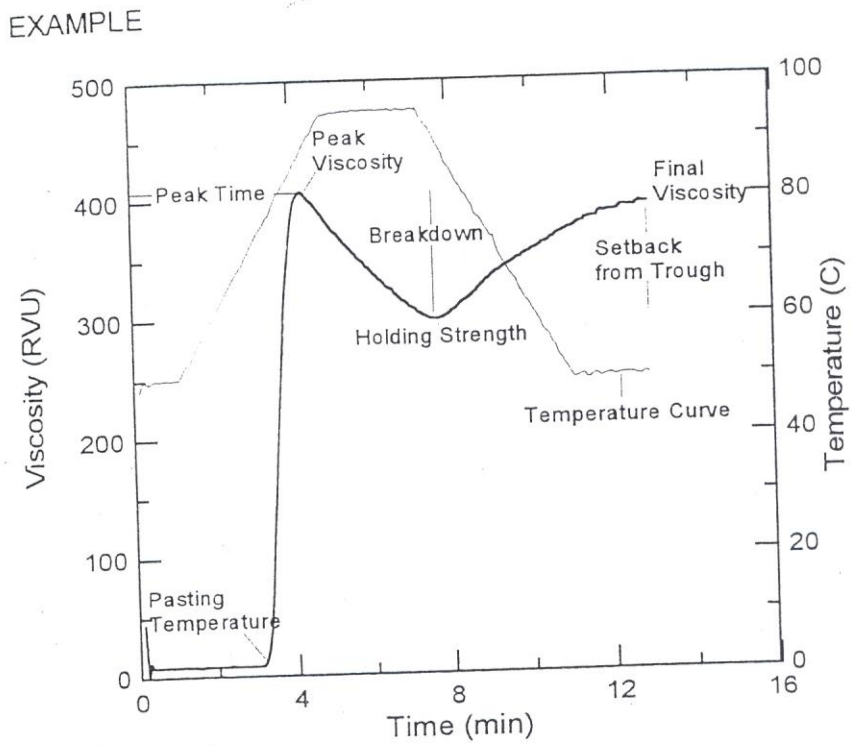

Figure 2.7 Sample representation of RVA curve showing the parameters obtainable down starches to provide sugars to help fuel the fermentation process, thus facilitating formation of gas by the yeast in the dough and reducing the viscosity of the dough, helping it to rise. The amount of enzyme present can have a direct bearing upon the quality of bread produced. When the alpha-amylase activity is right, high volume bread with firm and soft texture is achieved. If the activity is too high, a sticky bread crumb and low volume may result. If the activity is too low, a dry bread crumb with large holes may result (Anonymous, 2009). There is therefore a consensus that a certain amount of alpha-amylase is necessary for proper baking to occur. On the other hand, the extent of sprout damage and its influence on pasta cooking quality has generated much controversy (Dexter *et al.,* 1990). Studies have concluded that sprout damage either has no influence on pasta cooking quality (Donnelly 1980; Dick *et al*. 1974) or that the effects are subtle and only become apparent when sprout damage is severe (Dexter *et al.*, 1990; Matsuo *et al* 1999) Despite the evidence to the contrary, the belief persists among pasta alpha-amylase activity in flour. The falling number (FN) value has an inverse relationship with the alpha-amylase activity meaning the higher the alpha-amylase activity the lower the FN value, and vice-versa. Generally, a falling number value of 350 or greater indicates low enzyme activity. Values below 200 indicate high levels of enzyme activity.

Many North American and Japanese manufacturers demand a durum wheat falling number in excess of 300 sec for the manufacture of premium pasta products. Pasta processing problems attributed to sprout damage include uneven hydration and extrusion, strand stretching, and a high potential for checking and cracking upon storage (Donnelly 1980).

2.10 Physical and physicochemical properties of noodle and pasta

During pasta processing, semolina is subject to various physical and chemical modifications. The addition of water during mixing induces molecular mobility of semolina components, causing biochemical modifications of proteins, carotenoid pigments and oxidoreductase enzymes.

2.10.1 Noodle colour, moisture content, breaking strength

Colour is a major component of visual appearance of a produce or product, and an important indicator of quality, especially in food industries. Pasta colour is essential for assessing pasta quality and semolina contains both starch bound and non-starch lipids. Consumers generally prefer pasta with a bright yellow colour (Debbouz, *et al*., 1995) but during pasta processing, there is reduction in the intensity of the characteristic bright yellow colour, due to the oxidation of yellow pigments of durum wheat semolina catalysed by the enzyme lipoxygenase present in semolina. Processing operations during noodle and pasta production have great effect on the final colour of product, as much as the material input. Fortification of pasta with legume flour, for instance, significantly decreased brightness (L* value) of dried pasta probably due to the higher ash content of legume flours (Oliver *et al*., 1993). Similar effect was observed when pasta was fortified with green pea, chickpea and lentil flour (Wood, 2009; Zhao *et al*., 2005). A significant increase in redness (a* value) was also observed for pasta fortified with faba bean flour, without affecting the yellowness (b* value).

Drying temperature for noodle and pasta also has a bearing on the product colour. Increasing drying temperature decreased pasta brightness of split pea and faba bean dried pasta. This darkening was accompanied by a decrease in yellowness (lower b* value) and increase in pasta redness (higher a* value). Decrease in pasta brightness and increase in redness may be related to the development of Maillard reaction. Indeed, non enzymatic browning related to the Maillard reaction readily occurs during pasta drying, especially at high and very high temperatures (Anese, *et al*., 1999). Moss (1971) investigated the colour and cooking qualities of noodles, their whiteness and/or brightness throughout processing. Nielsen *et al*., (1980) reported that on cooking, both durum wheat pasta and legume fortified pastas, regardless of their drying profile, became bleached resulting in increased brightness (L* value) and decreased redness (a* value) and decreased yellowness (b* value).

Hardness or breakage susceptibility is another physical parameter of dried products, sometimes classified along with texture parameters, or as breaking strength (Yagci and Gogus, 2008). This is usually a measure of the force or energy required to penetrate or break a product. Zweifel (2001) described breaking strength as a measure of the homogeneity of a material and the density and continuity of the protein network which gives pasta its cohesiveness. Breakage susceptibility of dried spaghetti was related to the residual deformations (or residual stresses) released upon hydration (Chillo *et al*., 2008). For some extruded products such as snacks, consumed directly, a low value of hardness is desirable. Yagci and Gogus (2008), reported reduction in breaking strength of extruded snacks when partially defatted hazelnut flour was substituted with starch at low levels. Hardness could also be used to describe the texture of cooked sample, especially in terms of firmness, chewiness, elasticity, stickiness or adhesiveness (Haraldsson, 2010). Breaking strength is a measure for the homogeneity of the material its density and the continuity of the protein network which gives pasta its cohesiveness (Zweifel 2001). Kratzer (2007) reported the influence of extrusion rate on spaghetti breaking resistance, for instance, pasta produced in the twin-screw extruder at different extrusion 125 and 200 rpm had higher breaking strength than the spaghetti extruded at 50 rpm. Type of extruder used in pasta making play a part in its ability to resist breakage and also affects the cooking behavior. Cooking losses were reported lowest for single-screw extrusion; slightly higher for the spaghetti that was extruded in the cylinder-plunger system and highest for spaghetti extruded in the twin-screw extruder (Kratzer, 2007).

2.10.2 Dough properties and starch qualities

Pasta quality is dependent on the raw materials used, the production recipe and the production process (Dawe, 2001). Dough properties are essentially governed by its storage proteins which are determined by the dough strength, extensibility and dough stability. The chemical structure of dough and pasta largely depend on the concentration of storage proteins, particularly *globulins and prolamines*. These hydrophobic proteins (mostly soluble in alcohol/water mixtures) are a major source of essential amino acids, including methionine. Globulins have a marginal yet necessary role in dough formation, whereas ---Prolamines (gliadins and glutenins), which cover up to 50-60% of the total amount of protein, are rich in cysteine with free thiol groups (-SH) and disulfide bridges (RS-SR). These structural features form the basis for the rheological properties of dough i.e. its viscosity and elasticity.

Gliadins and glutenins are well-separated in the flour, they join when water is added, with their structure changing to make a new protein, gluten**.** Gluten is an essential compound for pasta production. Gluten formation is a very complex phenomenon involving several factors. First of all, when water is added, proteins become highly hydrated and assume a new 3-dimensional configuration in which hydrophilic regions face outward while hydrophobic regions face inward. Protein chains interact with each other. Water molecules bond to proteins through the breaking of some pre-existing bonds and the formation of new ones. The second essential condition for gluten formation is the addition of mechanical energy by doughing so that water is uniformly distributed among the flour particles, while in drawing near to each other, the proteins link to form disulfide bridges. Gliadins undergo deformation and extension because of their viscous properties, whereas glutenins cannot be deformed, thus ensuring durability, tear resistance, and elasticity. As a result, gluten is deformable yet durable and tear resistant. Dough is elastic due to the loops derived from the disulfide bridge formation and consequently the bending of protein molecules. Proteins stretch into filaments linked by hydrogen bonds and disulfide bridges, while gluten assumes an ever more regular structure, a new texture whose meshes trap starch granules and air bubbles. Once completely formed, the dough loses its former stickiness to become soft, velvet-like and deformable into a very thin film without breaking and tearing.

Another important factor in dough formation is the control of amylase activity. When water is added to the flour, the mixing action that occurs during dough development immediately triggers the hydrolytic activity of amylase enzymes. These enzymes split starch into simple carbohydrates that position themselves on the dough surface. As a result, pasta has a sticky, poor consistency. To avoid this drawback, devices such as appropriate modulation of mechanical action should be adopted during processing, water quantity, and dough temperature. In breadmaking, gluten must ensure extensibility &elasticity of dough, expanding and retaining the carbon dioxide gas formed during fermentation and baking (Liu *et al,* 1996). But, in pastamaking, gluten must be tenacious enough to retain the gelatinized starch granules during pasta cooking.

Also of great influence is the starch component, non-starch polysaccharides and non-gluten proteins (Sissons, 2008). The continuity and strength of the protein matrix formed during dough mixing and extrusion has great impact on the textural characteristics of the pasta. Mechanical texture is typically described by terms such as firmness, elasticity, stickiness, chewiness and bulkiness and can be measured by a sensory panel or by conducting objective tests.

Dough strength is desired to be just adequately strong enough to pass through the extruder intact. Protein quality was found to be of equal importance to noodle quality as protein content (Huang, 1996). Protein quality as related to bread baking has been extensively studied and well established, but little information regarding the protein quality requirements of wheat for production of Asian noodles is available (Park *et al.*,2003). Pastas have been nutritionally enriched with different protein sources, such as in soy-macaroni, enriched non fat milk macaroni etc (Peterson *et al*., 1986).

Starch quality, which dictates the pasting properties inherent in noodle flour, is also of importance. This has a bearing on the texture of noodle products and has been shown to be dependent on the gelatinized starch. A high starch paste viscosity is associated with good quality noodles (Kim, 1996). Peak viscosity and breakdown viscosity of flour have negative relationships with the hardness of noodles (Yun *et al* 1996; Baik and Lee, 2003) and positive relationships with cohesiveness of noodles (Baik and Lee 2003). Final paste viscosity has been related positively with the hardness of noodles (Yun *et al*., 1996; Baik and Lee, 2003). Certain properties such as chemical composition, physicochemical, pasting, thermal parameters and gel texture of noodle flours, were reportedly correlated with the cooking and textural qualities of vermicelli produced from such flours (Yoenyongbudagal and Noomhorm, 2002). Amount of hydration has been shown to affect physicochemical characteristics of spaghetti pasta (Abecassis *et al*., 1994).

2.10.3 Drying of noodle and pasta

Drying temperature is another key determinant of pasta and noodle quality. Noodle drying can be achieved by air drying, deep frying or vacuum drying. Hou and kruk (1998) studied drying of noodles extensively and reported that regular dry noodle strands of a certain length are manufactured and hung on rods in a drying chamber with controlled temperature and relative humidity. Air drying, they reported, involves multistage processes. In the first stage, noodles are dried at low temperature (15-20 ^{o}C) and moisture content is reduced from 40-45% to 25-27%. In the second stage, air of 40 ^{o}C and 70-75% relative humidity is used to ensure moisture migration from the interior of the noodle strands to outside surfaces and finally the product is further dried using cool air. Noodles prepared and dried this manner stand the risk of mold infestation, discoloration and spoilage (Ihenkoroye and Ngoddy, 1985; Oladunmoye *et al*., 2002). On the other hand, at very high temperatures, moisture migration occurs at a fast rate and resulting pasta become brittle to touch. Oladunmoye *et al*., (2002) reported that direct oven drying, of freshly produced noodles, without initial air drying, made noodles shrink tremendously and very brittle to touch. When pasta is dried at low temperature (<40^{o}C), protein content and gluten strength assume equal importance in determining pasta quality. Hence, intrinsic differences in quality are reflected in both surface characteristics associated with stickiness and firmness. At high temp (>70%) drying, protein content will be important in determining firmness. Many reports have indicated that the application of high drying temperatures in pasta processing increases the quality of durum wheat pasta (lower cooking loss, lower stickiness, higher firmness) (Baiano and Nobile, 2006; Zweifel, *et al*., 2003). High drying temperatures can therefore be used to improve the culinary and sensorial properties of fortified pasta and composite pastas.

Manthey and Scorno (2002) reported that cooking quality of pasta containing nontraditional ingredients is generally improved by drying at high or ultrahigh temperatures. Although, high temperatures denatures protein associated with the gluten matrix, which subsequently protects starch granules from rupturing during cooking, yet high temperature drying reduces water permeability, cause small changes in the packing and arrangement of starch granules, thus contributing to decreased cooking loss and increased cooked firmness (Yue *et al*., 1999).

2.10.4 Cooking of noodle and pasta

During cooking of pastas, the starch and proteins play completely different roles. The starch granule absorbs water and rapidly swells up until it breaks and frees its content in the water; the two gluten proteins on the other hand coagulate forming a very compact lattice that envelopes the starch granules and tries to hold them as much as it can. These two contrasting transforming behaviours take place under same temperature. While the starch tends to absorb water, swelling till it breaks, the protein grid that, coagulating, tries to stop the complete dispersion of the starch. In poorly prepared pasta, the starch out balances the protein element and the pasta turn out to be a rigid piece of wheat with whitish water. Pasta that is prepared with well balance of the elements is a soft and spongy one as the gluten has managed to stop the starch from absorbing water. Thus the internal balance, nutritional value and taste of pasta are preserved.

Cooking quality is one of the most important criteria for assessing the acceptability of noodle products. This is determined by two independent parameters: visco-elastic behaviour (i.e. firmness after cooking), and the surface condition of the cooked pasta (D'Egidio *et al*., 1982; Dexter *et al*., 1983; Autran *et al*., 1986). Cooking of noodles has been described to involve boiling in water (Kim and Wiessenborn, 1996), or soaking prior to boiling in water (Kim *et al*., 1996). Cooking occurs at the surface of noodle and proceeds toward the center. The starch at the surface continues to swell, and some of it gradually disperses into the cooking water. When noodles are overcooked, the starch granules near the surface gain too much water and become paste-like, resulting into loss of starch into cooking water, loss of firmness, and increased stickiness. Hence, cooking time should be optimized to achieve a desirable product texture.

Optimal cooking time corresponds to the time taken for the disappearance of white coloration in the central core of the macaroni noodle when squeezed gently between two glass plates (Manthey and Schorno, 2002). Cooking quality is characterized by cooked weight, cooking loss, weight and volume gains. Cooked firmness and stickiness are also reportedly important (Lee *et al*., 2002) for noodles. Optimal cooking time, water absorption index, swelling volume, tolerance to overcooking and acceptability to consumers in taste and appearance are equally important quality indices for assessing noodle products. A high weight and volume gain and a low cooking loss are desirable for noodle products (Lee *et al*., 2002).

2.10.5 Sensory/eating qualities

Huang (1996) predicted the eating qualities of white salted Chinese noodles in terms of its firmness and chewiness, using dough stability, degree of softness, resistance and extensibility. Nonetheless, experimental tests backed up by sensory assessment with use of panelists, scoring for taste, appearance, texture and acceptability is still the most reliable judgment of quality (Cubadda, 1988, Lee *et al*., 2002). Sensory characteristics of glossiness, transparency, firmness, stickiness and elasticity, were defined by Kim and Wiesenborn (1996) when studying starch noodle quality as related to potato genotypes (Table 2.10).

The ISO system (1985) proposed standard definitions for pasta quality in two sensory attributes: surface condition after cooking and firmness. Cooked starch noodles are nonetheless desired neither to be too firm or too soft in texture, not too high or too low in chewiness; but desired to exhibit transparency and surface slipperiness (Kim and Wiesenborn, 1996; Kim *et al*., 1996). More recently though, noodle quality was considered in terms of its physicochemical properties as comprising of: solid loss during cooking and water uptake or swelling ratio during cooking. Solid loss is determined by cooking noodles in boiling water for 10 minutes. Cooked material is strained into a beaker, and the whole filtrate is transferred quantitatively to a tarred Petri dish and evaporated over a water bath, followed by drying in an oven at 105 ^{o}C for 3hours and weighing the solid left. A solid loss of less than 6% is considered very good; about 8% is average. Cooked noodles are weighed separately to obtain water uptake (g/g) or swelling ratio (Sowbhagya and Zakiuddin, 2001).

The Borazzio cooking test has considerable acceptance in Europe: i.e. Two hundred and fifty grams of dry product is cooked in 1% salt solution in each of two cooking vessels heated to 103.3 ^{o}C (218 ^{o}F). Products are cooked at 97.8 ^{o}C (208 ^{o}F) to minimize disintegration of product. Cooking time of 18 and 28 min is used for the two vessels. Samples are drained for 5 min. and weighed. Difference in weight between dry and cooked product is recorded as water absorption during cooking. Volumes of dry and cooked sample are determined by water-displacement method. Water in which sample has been cooked is placed in a graduated glass tube and the suspension of starch and other materials is allowed to settle for 30 min, height of milky portion is measured (Sowbhagya and Zakiuddin, 2001). Cooking quality characteristics in terms of cooking loss, weight and volume gains are hence important for noodles. A high weight and volume gain and a low cooking loss are desirable for noodle products (Lee *et al*., 2002).

Table 2.10 Sensory attributes of cooked starch noodles determined in sensory evaluation

Sensory Attributes	Definitions
Glossiness	The degree of shininess or brightness of the surface of the cooked starch noodles
Transparency	Extent of visibility through the cooked starch noodle strands.
Firmness	The amount of force required to bite through the cooked starch noodle strands
Stickiness	The amount of force required to remove starch noodle strands which adhere to the teeth
Elasticity	The degree to which starch noodle strands recovers their original shape after deformation by the teeth
Chewiness	Length of time required to masticate one strand of sample at a constant rate of force application to reduce it to a constituency suitable for swallowing.

Source: Kim and Wiesenborn (1996); Kim *et al*. (1996)

Texture of cooked noodles can be measured instrumentally by using a TA-XT2 texture analyzer (Texture Technologies Corp., Scarsdale, NY), or assessed subjectively by trained panelists. Organoleptic evaluation can be carried out using trained panelists to assess sensory properties of cooked noodles.

Nonetheless, experimental tests backed up by sensory assessment with use of panelists, scoring for taste, appearance, texture and acceptability is still considered the most reliable judgment of quality (Cubadda, 1988; Lee *et al*., 2002).

2.10.6 Nutritional/proximate composition

Noodles made from whole durum wheat is more nutritious than those from its semolina fraction, due to the removal of proteinous bran and germ in the latter during milling and extraction (Douglass and Mathews, 1982). Hence, an appropriate balancing need be sought between nutritional values and organoleptic acceptability. Nutrients such as vitamins, proteins, and amino acids, are required for our bodies to function properly. These nutrients are dependent upon minerals which are predominantly obtained from the food we eat. The main elements (Na, K, Ca, Mg, Cl, P) are essential for humans in amounts >50 mg/day, while trace elements (Fe, I, F, Zn, Se, Cu, Mn, Cr, Mo, Co, Ni) are essential in concentrations of <50 mg/day (Northen, 2006). Acute deficiencies in these minerals in needed proportions often trigger degenerative diseases ranging from weight gain to mental apathy or liver problems (Northen, 2006).

Nutritional survey data indicate the prevalence of malnutrition in Nigeria, especially among the pre-school children of 3 to 7 years of age (Maziya-Dixon *et al.*, 2004). A diet that balances carbohydrate component with protein content is ideal for African growing children. A good content of mineral nutrients such as the macro minerals (calcium, magnesium, phosphorus, potassium and sodium) and trace elements (chromium, copper, fluoride, iodine, iron, selenium, and zinc) are desirable and vital for healthy growth of children and many cellular activities in adults (FAO, 2004b; Addo, 2005; Ikewuchi and Ikewuchi, 2009). Data on the nutrient content of dry enriched macaroni and noodle products is shown in Table 2.11.

Table 2.11 Nutrient content of dry enriched macaroni and noodle products made from durum wheat

Nutrient (per 100g)	Macaroni Products*	Noodle Products*	Pasta**
Proximate Composition(g)			
Moisture	5.2-12.0	7.9-11.5	9.8
Protein (Nx5.7)	12.1-14.2	12.0-14.4	10.7
Fat	0.2-2.6	3.1-5.6	1.8
Carbohydrate	75.1	71.7	76.89
Crude Fiber	0.3-0.6	1.2-0.5	
Ash	0.6-0.8	0.7-1.1	0.81
Macrominerals(mg)			
Calcium	16-32	30-44	22.00
Magnesium	41-52	61-126	51.00
Phosphorus	138-148	150-261	189.00
Potassium	140-159	190-194	192.00
Sodium	4-20	19-24	
Trace Minerals			
Iron(mg)	3.17-7.02	2.20-5.97	1.40
Zinc(mg)	0.71-1.09	1.30-1.87	1.15
Copper(mg)	0.220-0.396	0.240-0.342	0.32
Manganese(mg)	0.489-0.542	0.690	
Selenium	50-142(µg)	57-113(µg)	2.70mg

Sources: *Douglass and Mathew's (1982)
** Marconi *et al.* (1999)

Non-traditional ingredients have been incorporated into pasta/noodles to improve nutritional benefits and to expand the use of local raw materials (Marconi and Carcea, 2001). In order to improve noodle taste and nutritional value, Huang (1996) suggested that wheat based noodles be enriched with egg, milk, fish stock, butter, spinach juice, chicken broth or calcium, though these were optional ingredients used as desired. Lee *et al.* (2002) enhanced β-carotene content in Asian noodles by adding pumpkin powder, a good vegetable source while Sinha and Manthey (2008), added flaxseed flour, for its rich content of omega-3 fatty acid. Other non-traditional ingredients that have been reportedly incorporated into noodles include flours of finger millet, cowpea, coconut, soybean, bambara groundnut etc (Sowbhagya and Zakiuddin, 2001; Gunathilake and Abeyrathne, 2008; Sinha and Manthey, 2008). Some of these flours, apart from imparting nutritional benefits, also improve dough extrudability.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Acquisition of raw materials

High starch yielding, low-cyanide cassava roots of improved cultivar, TMS 30572 (1 year old), were obtained from International Institute of Tropical Agriculture (IITA), Ibadan. Durum wheat semolina was obtained from Flour Mills of Nig. PLC, Apapa, Lagos. Soybean grains were obtained from Agege main market. Food binders/stabilizers used include gum Arabic and gelatin. Other noodle-making additives used (pure analar grade sodium and potassium carbonates) were obtained from Finlab Chemical Company in Lagos while ascorbic acid was obtained from Crop utilization unit of IITA, Ibadan. While cassava and soybean were being processed, durum wheat semolina, noodle-making additives, were kept dry and sealed in low-density-polyethylene films in a refrigerator at 4°C during the course of this study.

3.1.1 Processing of cassava into starch

Unfermented, detoxified starch was prepared from IITA improved cassava cultivar, TMS 30572 following standard procedures as developed and adopted by Federal Institute of Industrial Research, Oshodi (FIIRO) (FIIRO, 2006). Cassava root was washed, peeled, weighed, grated or pulped and processed into starch within 24 hours of harvest. Processing was carried out in the pilot plant of FIIRO, Lagos using the established flow process shown in Fig. 3.1. These were kept dry and sealed in low-density-polyethylene films in a refrigerator at 4 °C during the course of this study.

3.1.2 Processing of soybean flour

Soybean obtained from Agege main market was processed into high quality soy-flour (HQSF) using a combination of FIIRO developed methodology (Oladunmoye *et al.*, 2004) and that advocated by IITA for fortification purposes (IITA, 1992) as shown in Fig 3.2 at the Crop Utilization Unit of the Institute of Tropical Agriculture (IITA), Ibadan. The soybean flour was sealed and kept dry in low-density-polyethylene films in a refrigerator at 4 °C during the course of this study.

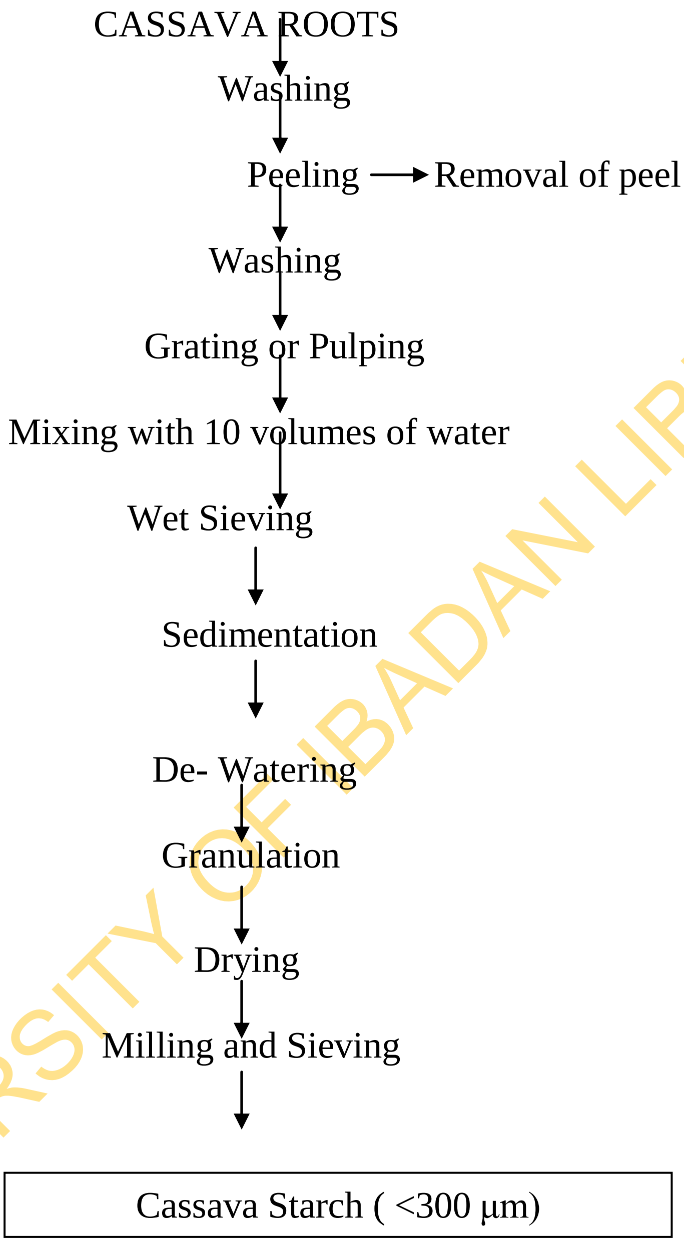

Figure 3.1 Flow chart for the production of cassava starch
Source: FIIRO (2006)

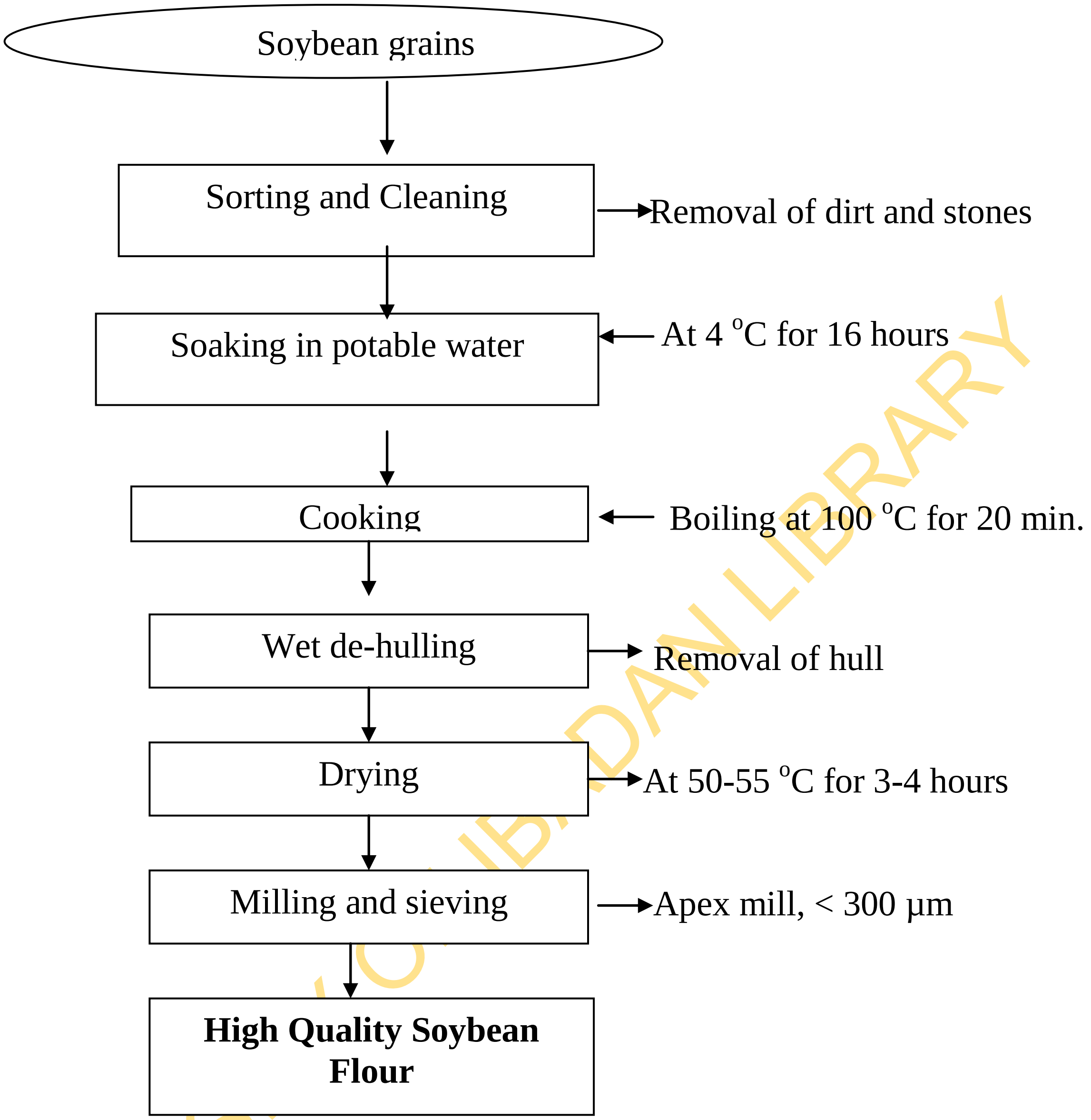

Figure 3.2 Flow chart for the preparation of high quality soybean flour

3.2 Determination of properties of prepared cassava starch, durum-wheat semolina, and their blends

Cassava starch was adequately mixed with durum wheat semolina portions in pre-determined mixing ratios of 0/100, 20/80, 30/70, 50/50, 70/30, 100/0 using the mixing section of De-Longhi Pasta Italia (classic, model 700, made in Italy, Plate 2.2) extruder. The resulting six (6) flour samples were sealed and kept dry in low-density-polyethylene films in a refrigerator at 4 ^{o}C for analytical purposes.

3.2.1 Particle size distribution

Particle size distributions of cassava starch and durum wheat semolina were determined using sieve analysis method on a sieve cascade (Retsch Vibrosieb- AS 200 basic Mechanical shaker, Germany) (ASTM, 2006). Procedure followed was as described by Kratzer *et al* (2007). The cascade was loaded with 100 g of flour samples and sieving was carried out for 5 min at shaking amplitude of 80 and the remainders on each of the sieves was weighed each time. The used sieves test sieves had mesh size openings of 630, 300, 250, 180, 150 µm to base. Weight retained on each sieve after 5 minutes shaking was noted each time. Measurement was done in duplicate.

3.2.2 Proximate composition

3.2.2.1 Determination of moisture content and dry matter

The moisture content of the samples was determined using AOAC (2005) method by weighing 3 g of each sample into pre-weighed and zeroed, clean drying plates. The cans with the samples were then placed in a hot-air oven (Fisher Scientific Co. USA), model 655 F, maintained at 105 °C. After 16-18 hours, the drying plates were transferred into a desiccator to cool, after which the final weight was taken. Moisture content was calculated as in equation 3.1

$$\% \text{ Moisture content (MC)} = \frac{W_2 - W_1}{S} \times 100 \qquad \text{……….} (3.1)$$

Where:

W_1 = Weight of empty moisture content can.

W_2 = Weight of dried sample with moisture content can.

S = Weight of sample.

$$\% \text{ Dry matter (DM)} = 100\text{-MC} \qquad \text{……………….. } (3.2)$$

3.2.2.2 Determination of Ash Content

This was carried out using AOAC (2000) method, which involved weighing 2 g of the samples into a crucible (which had been previously dried to constant weight at 600^{o}C), and weighed. The crucible containing the sample was then placed on a hot plate inside the fume cupboard to char the organic matter. The remaining residue (inorganic matter) was transferred into the muffle furnace (Fisher Scientific Co. USA), model 186A maintained at 600 °C for 6 hours to ash the samples completely. The crucibles were transferred into a desiccator to cool, and thereafter weighed.

$$\% \text{ Ash content} = \frac{W_3 - W_1}{W_2 - W_1} \times 100 \qquad \ldots\ldots\ldots\ldots\ldots (3.3)$$

Where:

W_1 = *Weight of crucible.*
W_2 = *Weight of crucible + sample before ashing.*
W_3 = *Weight of crucible + sample after ashing.*

3.2.2.3 Determination of Crude Protein Content

Crude protein was determined using Kjeldahl method (AACC 2005, Method 46-12.01). Exactly 0.2 g of sample was weighed into digestion tube and one tablet of Kjeldahl catalyst (copper) and 4 mL of conc. H_2SO_4 were added. This was transferred into a fume cupboard and 4 mL of H_2O_2 was added, fuming was allowed to stop. The mixture was placed on Tecator digestion block pre-set at 420 ^{o}C and digested for 1 hour; at the end of which all organically-bound nitrogen is converted to ammonium hydrogen sulphate. With the addition of a strong alkali (NaOH, 40%) and the application of heat, ammonia NH_3 is distilled out, and is collected in 1 % boric acid receiver solution containing bromocresol green/methyl red indicator. Blanks were prepared and treated similarly. Rack of digestion tubes was removed from the block and allowed to cool to room temperature.

The tube containing the blank sample was placed in the distillation unit of the system, and the weight of the sample to be analyzed was entered using the key board on the system and the system was allowed to automatically perform the distillation and titration of the sample. Likewise, in turns, the tubes containing the samples' digest were placed in the distilling unit of the system. The system was released to automatically perform the distillation and titration as programmed. Results were displayed automatically at the end of each analysis according to equation 3.4

Calculation:

$$\% \text{ Total Nitrogen} = \frac{(\text{sample titre} - \text{blank titre}) \times N \times 14.007 \times 100}{\text{Sample weight (mg)}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.4)$$

$$\% \text{ Protein (crude)} = \% \text{ Total Nitrogen} \times \text{Conversion factor.} \quad \ldots\ldots\ldots\ \ldots\ldots\ldots\ldots (3.5)$$

N = Normality of the acid.

3.2.2.4 Deternination of Crude Fat Content

An automated method (Soxtec System HT2; AACC, 2005) was used to determine crude fat. About 2-3 g of sample was weighed, tranfered into a clean thimble plugged with cotton wool and inserted into the Soxtec. HT apparatus. Clean pre-weighed extraction cup containing 25-50 mL hexane was placed on the heating mantle of the apparatus previously heated up to 120 ^{o}C; and then the thimble containing the sample was lowered into it. This set up was left in this boiling position for 15 min. After the extraction, the thimble (i.e. sample) was lifted up and left in the rinsing position for 45 min. Thereafter, air knob is turned on and the hexane is allowed to evaporate for some 10mins. Extraction cup is further dried in hot-air oven for 20-30 min. at 105 ^{o} C to rid it of residual hexane. This was cooled in the dessicator and weighed. Fat content was calculated as follows:

$$\% \text{ Fat} = \frac{[(\text{wt of cup} + \text{fat}) - \text{wt of empty cup}]}{\text{wt of sample}} \times 100 \quad \ldots\ldots\ldots\ \ldots\ldots\ldots (3.6)$$

3.2.2.5 Determination of Carbohydrate content

Carbohydrate content was estimated by difference.

3.2.2.6 Determination of Energy content

Energy was calculated using Atwater's factors.
Energy = 9 (Fat) + 4 (Protein) + 4 (Carbohydrate) ……. …….(3.7)

3.2.2.7 Determination of Physical and Physicochemical properties

3.2.2.7.1 Bulk density

This was determined by measuring the packed volume of a known weight of sample (Wondimu and Malleshi, 1996). Ten grams of sample was weighed into 50 mL graduated measuring cylinder. The samples were packed by gently tapping the cylinder on the bench top 10 times from the height of 5 cm and the volume of the sample was recorded.

Calculation:

$$\text{Bulk Density} = \frac{\text{Wt of sample after tapping}}{\text{Volume of sample}} \quad \ldots\ldots\ldots\ldots\ldots(3.8)$$

3.2.2.7.2 Colour measurement

Colour was determined using a colour measuring instrument (Color Tec-PCM, model SN 3000421, USA). The colorimeter operates on the CIE (Commission Internationale de l'Eclairage) colour scheme, and values are expressed on the L*, a*, b* tristimulus scale. The instrument was initially standardized (L=87.68, a=2.15, b=4.16) using a white reference standard (Onward white duplicating paper sheet, 80 g/m^2). Duplicate measurements were made on sample packaged in transparent polythene films (Nasco whirl-pak); with the meter-sensor touching the sample surface. Readings were defined in three directions: a Light to Dark direction, called 'L', a Red to Green direction called 'a' and a Blue to Yellow direction called 'b' (AOAC 2006).

3.2.2.7.3 Determination of amylose and amylopectin contents

These were determined using the method of Juliano (1971) which involved the preparation of stock iodine solution and iodine reagent. First 0.1 g (100 mg) of the samples was weighed into a 100 mL volumetric flask, and then 1 mL of 99.7–100% (v/v) ethanol and 9 mL 1N sodium hydroxide (NaOH) were carefully added. The mouth of the flask was covered with parafilm or foil and the contents were mixed well. The samples were heated for 10 min in a boiling water bath to gelatinize the starch (the timing was started when boiling began). The samples were removed from the water bath and allowed to cool very well, then made up to the mark with distilled water and shaken thoroughly. This was followed by pipetting 5 mL into another 100 mL volumetric flask and 1.0 mL of 1N acetic acid and 2.0 mL of iodine solution were then added. The flask was topped up to the mark with distilled water. Absorbance (A) was read using a spectrophotometer at 620 nm wavelength. The blank contained 1ml of ethanol, 9 mL of sodium hydroxide, boiled and topped up to the mark with distilled water. Finally, 5 ml was pipette into a 100 ml volumetric flask, 1 mL of 1N acetic acid and 2 mL of iodine solution were added and topped up to the mark. This was used to standardize the spectrophotometer at 620 nm.

The amylose content was calculated as:

Amylose content (%) = 3.06 × A × 20…………….. (3.9)

Where: A = Absorbance value

While amylopectin content was calculated as:

Amylopectin content (%) = 100- Amylose content (%) ………. ……..(3.10)

3.2.2.7.4 Determination of free sugars and starch content

The method of AOAC (1990) was used. Finely ground samples (0.02 g) were weighed into centrifuge tubes and 1 mL of ethanol was added followed by 2 mL of distilled water and 10 mL hot ethanol. The mixture was vortexed and centrifuged using Sorvall centrifuge (Newtown, Conneticut, USA, model GLC-1) at 2000 rpm for ten minutes. The supernatant was collected and used for free sugar analysis, while the residue was used for starch analysis. To the residue, 7.5 mL perchloric acid was added and allowed to hydrolyze for 1 hour. It was diluted to 25 mL with distilled water and filtered through Whatman no 2 filter papers. From the filtrate, 0.05 mL was taken, made up to 1 mL with distilled water, vortexed and developed for color and the absorbance was read on a spectrophotometer (Milton Roy Company, USA), model Spectronic 601 at 490 nm wavelength.

On the other hand, the supernatant for sugar analysis was made up to 20 mL with distilled water; an aliquot of 0.2 mL was taken and 0.5 mL (5% phenol), followed by 2.5 mL concentrated sulphuric acid were added. The sample was allowed to cool and the absorbance read on a spectrophotometer.

$$\textbf{\% Sugar} = \frac{\text{Abs} - \text{Intercept} \times \text{Dilution factor} \times \text{Volume}}{\text{Weight of sample} \times \text{Slope} \times 10,000} \quad \text{……… ………}(3.11)$$

Where:
Abs. = Absorbance; Dilution factor = 5; Volume = 20; Slope = 0.0055, and Intercept = 0.0044

$$\textbf{\% Starch} = \frac{\text{Abs} - \text{Intercept} \times \text{Dilution factor} \times \text{Volume} \times 0.9}{\text{Weight of sample} \times \text{Slope} \times 10,000} \quad \text{…. ……….}(3.12)$$

Where:
Abs. = Absorbance; Dilution factor = 20; Volume = 25; Slope = 0.0055, and Intercept = 0.0044

3.2.2.7.5 Measurement of diastatic activity

Diastatic activity of starch and flour blends was determined using standard American Association of Cereal Chemists method (AACC, 2000). Buffer solution (46 mL) was added to 5 g of sample in a clean conical flask. Buffer solution was made by dissolving 3 mL glacial acetic acid, 4.1 g anhydrous Na acetate and 4.5 mL H_2SO_4, specific gravity 1.84 and diluted to 1 litre with distilled water. This was placed in a water bath for one hour at 30 ^oC, and shaken at 15 minutes intervals. To this mixture; 2 mL H_2SO_4 (10%), and 2 mL sodium tungstate was added, shaken and poured into a filter paper. About 10 mL of ferric cyanide solution was measured into the emptied conical flask and 5 mL of each filtrate was added. This mixture was placed in a water bath at 100^{o}C for 20 mins, and thereafter cooled to ambient temperature. To this, 25 mL acetic acid salt solution and 10 mL starch iodide was added as indicator. This was titrated against 0.1N sodium thiosulphate solution until a colour change from blue-black to white was observed at endpoint. Maltose figure was then obtained from a Thiosulfate-Maltose (diastatic activity) Conversion Table, using the titre value obtained. Values obtained were expressed as mg. maltose per 10 g flour.

3.2.2.7.6 Determination of alpha-amylase activity

Alpha-amylase activity was determined using the Falling Number system (AACC, 1995) which is based on the ability of alpha amylase to liquefy a starch gel. Falling Number refers to the time in seconds required to stir and allow stirrer to fall a measured distance through a hot aqueous flour or meal gel undergoing liquefaction.

Referring to a standard (ICC standard No 107/1, 1995), the required sample weight corresponding to 7g at 14% moisture; flour portions were weighed in duplicate into Falling Number test tubes. To these, 25 mL distilled water was added, shaken several times and loaded onto the Falling Number equipment. Values were displayed at the end of each determination.

3.2.2.7.7 Determination of cyanide content

Cyanogenic potential (CNP) was determined using the automated enzymic method developed by Rao and Hahn (1984) and modified by Bokanga (1995). Sample was extracted with cold orthophospheric acid (0.1 M) and the extracts were mixed with phosphate buffer (pH 7.0) in a 5-turn glass coil. Diluted linamarase containing about 3 enzyme units per mL was then added to the samples and allowed to hydrolyze the bound cyanide (cyano-substituted glycosides) while being mixed with the samples in a long heating bath coil (exactly 5minutes), which was maintained at 27 ^{o}C. Sodium hydroxide (0.2 M) was then added to the stream to raise the pH as the cyanohydrin dissociates to HCN very rapidly above pH 6. The sample was then passed through a 15 cm dialyser. The cyanide ion, which diffuses through the dialyser into a stream of NaOH (0.01 M), was then reacted with buffered chloramine T to form cyanogen chloride (CNCl). The

CNCl then reacts with the isonicotinate colour reagent to give a red complex, which subsequently changed to blue. Two delay coils (20 turns each) were inserted in the system at this point to allow a stable change of colour from red to blue which was finally detected in a 15 x 2 mm flow cell (colorimeter) with 605 interference filters and recorded on a pre calibrated chart. The chart was calibrated using linamarin standards (20 ppm, 40 ppm, 60 ppm and 80 ppm). The baseline on the chart was set at zero units with all the reagents passing through the flow cell and the sampler probe taking in 0.1 M orthophosphoric acid in place of sample extract or linamarin standard. Each sample was analyzed in duplicate. The amount of linamarin in each sample was estimated by comparison with the linamarin calibration standard curve.

3.2.2.7.8 Determination of Pasting Properties

Pasting properties were determined by an adaptation of the AACC 2005 method 61-02.01, using a Rapid Visco Analyser 3 C (RVA, model 3C, Newport Scientific PTY Ltd, Sydney, Australia). About 3.0 g of sample were weighed into a canister and 25 mL of distilled water was dispensed into it. The slurry was heated from 50 °C to 95 °C with a holding time of 2 minutes followed by cooling to 50 °C with 2 min holding time. The rate of heating and cooling were at a constant rate of 11.25 °C/min. Peak viscosity, trough, breakdown, final viscosity, set back, peak time, and pasting temperature were read from the pasting profile with the aid of Thermocline for Windows Software connected to a computer (Newport Scientific, 1998).

3.2.2.7.9 Swelling power and solubility

These were determined by the modified method reported by Riley *et al*. (2006). Starch (1.0 g) was weighed into 100 mL conical flask; 15 mL of distilled water was added and mixed gently at low speed for 5 min. The slurry was heated in a thermostatic water bath (THELCO model 83, USA) at 80 ^{o}C for 40 minutes. During heating, the slurry was stirred gently to prevent dumping of the starch. The content was transferred into a pre weighed centrifuge tube and 7.5 mL distilled water was added. The tubes containing the paste were centrifuged at 2,200 rpm for 20 minutes using SORVALL GLC-1 centrifuge (model 06470, USA).

The supernatant was decanted immediately after centrifuging into a pre-weighed can and dried at 100 °C to constant weight. The weight of the sediment was taken and recorded.

$$\text{Swelling power} = \frac{\text{Weight of sediment}}{\text{Sample weight-Weight of soluble}} \quad \text{.............................. (3.13)}$$

$$\text{Solubility index (\%)} = \frac{\text{Weight of soluble x 100}}{\text{Weight of sample}} \quad \text{..............(3.14)}$$

3.2.2.7.10 Water absorption capacity (WAC)

This was determined using the method described by Sosulski (1962). To 1 g of the sample was added 15 mL-distilled water in a pre-weighed centrifuge tube. The tube with its content was agitated on a Flask Gallenkamp shaker for 2 minutes and centrifuged at 4,000 x g for 20 minutes on a SORVALL GLC-1 centrifuge (Model 06470, USA). The clear supernatant was discarded and the centrifuge tube was weighed with the sediment. The amount of water bound by the flour was determined by difference and expressed as the weight of water bound by 100 g dry flour.

3.2.2.7.11 Water - binding capacity (WBC)

To 1.25 g of starch in a pre-weighed 100 mL centrifuge bottle, 18.75 mL of distilled water was added. This was agitated on a wrist action shaker for 1 hour and then centrifuged at 2,200 x g for 10min. Water was decanted from the bottle and the bottle drained for about 10mins. Centrifuge bottle and starch sediment was then weighed. Amount of water bound by the starch was determined by difference. Water binding capacity of the starch was calculated as:

$$\text{Water binding capacity (WBC) \%} = \frac{\text{Grams bound water x100}}{2.5} \quad \text{……………………(3.15)}$$

Each sample was analysed in duplicate.

3.2.2.7.12 Measurement of level of starch damage

Starch damage measures the level of damaged starch in microampere and is defined as the weight (in grams) of starch available for hydrolysis per 100 g sample on 14% moisture basis. This was determined using standard AACC method (1995). The absorption rate was the amount of iodine absorbed by flour suspension in percentages while the time it took for this to occur was the absorption speed in seconds.

3.2.2.7.13 Determination of mixing properties and stability

This was done using the Brabender Extensograph (AACC, 1992). About 300 g of different flour blends were weighed, mixed with water and introduced into the equipment. Following programming, the equipment charted farinogram curves and furnished data on farinograph water absorption, energy, resistance to extension, extensibility, maximum resistance, and ratio number of the flour blends.

3.3 Production of cassava-wheat semolina macaroni noodles

In this study, six (6) different flour samples of cassava starch and durum wheat semolina, prepared on a replacement basis were used at three (3) hydration levels to develop macaroni noodles i.e. at low, medium, and high hydration. The processing steps adopted by Yoenyongbuddhagal and Noomhorm (2002) for rice flour noodles, that of Lan and Ilagantileke (1992) for the manufacture of transparent sweet potato noodles, that adopted by Kim *et al*. (1996) for starch noodles, and that developed by Oladunmoye *et al.* (2002) for cassava and cocoyam noodle products were synchronized, modified and simplified for cassava-wheat semolina macaroni production. Blends of cassava starch (CS), durum wheat semolina (DWS) and high-quality soybean flour (HQSF) were mixed in pre-determined ratio. The operational flow chart developed and adopted for cassava-semolina macaroni production is as shown in Fig. 3.3.

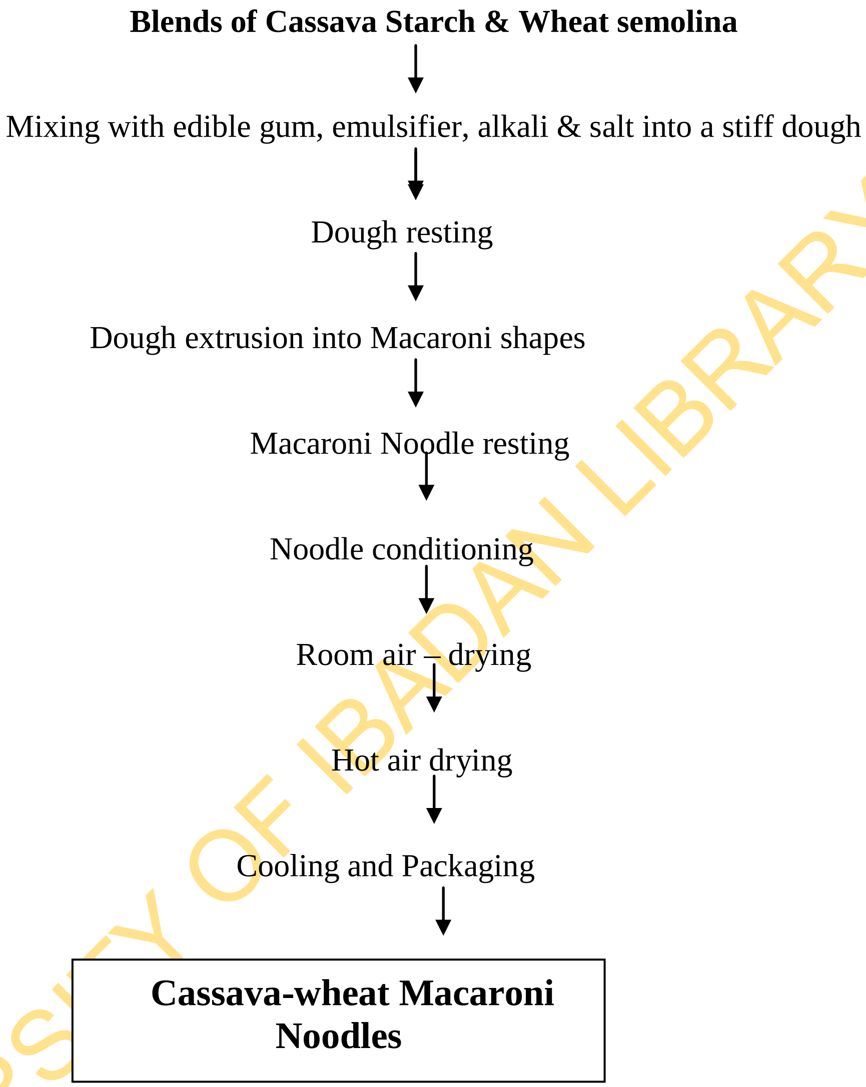

Figure 3.3 Flow chart for cassava-semolina macaroni noodle production

3.3.1 Unit operation descriptions

Mixing

Cassava-semolina blends were mixed (as dry particulates) with high-quality-soy-flour (HQSF, 5 g/100 g flour blend) in the mixing section of pasta extruder (De Longhi Pasta Italia, 700S) (Plate 2.2) for 5 min. To 100 g of each flour blend, 2 g gum Arabic, 3 g gelatin, 0.1 g of carbonates of Na and K, 0.5 g ascorbic acid, 1.5 g iodized salt and 0.3 mL of egg-yellow colour gel was weighed out and mixed, as noodle improvers (Oladunmoye *et al*., 2004). Boiling water was measured out as pre-determined amount to obtain 45, 50, 55% hydration and used to activate/dissolve weighed portions of noodle improvers; and then added to hydrate the mixed flour sample. Mixing was continued for 25-30 minutes at a mixer-blade rotation of 22 revolutions per min., at the end of which moderately stiff and consistent dough was obtained.

Dough resting

Dough was rested for half an hour, wrapped in low-density polyethylene film to prevent surface drying/caking prior to extrusion.

Dough extrusion into macaroni noodles

Rested dough at ~ 32^{o}-35^{o}C was thereafter fed into the extruder portion of De Longhi Pasta Italia, whose shaft rotates at 18 revolutions/min, and was extruded as macaroni shape through Teflon coated brass die (Plate 2.2).

Macaroni noodle resting and conditioning

Extruded noodles were allowed to rest for 1-1½ hrs on a constructed noodle dryer (wire – net on wooden frame, Plate 2.3), prior to hot-water conditioning. Noodles were submerged for 60 s in boiling water in a regulated water bath maintained at 100 ^{o}C (Oladunmoye *et al*., 2002).

Drying of macaroni noodles

Conditioned macaroni noodles were first air-dried at ambient temperature (24-28 ^{o}C) for 16-18 hours on the constructed netted wooden frames, before final drying in hot-air oven at 70-75 ^{o}C for 2-3 hours to a moisture level target of ~ 7-10%. Dried noodles were cooled and packaged in low-density polyethylene films, Nasco whirl-pak (ISO 9001 certified, USA).

Plate 2.2. Picture of De-Longhi Pasta Italia extruder

Plate 2.3. Constructed wooden frame for 2-way air drying at ambient temperature.

3.3.2 Evaluation of cassava-semolina macaroni dough and noodles

Doughs obtained after each extrusion was evaluated for moisture content, colour (as outlined in sections 3.2.2.1 & 3.2.3.2) and pH.

Dried macaroni noodles were packaged in moisture- proof Nasco whirl-pak (180z.1532 ML Plain; ISO 9001 certified), USA and labeled ready for analysis. Packs were stored in a refrigerator at 4 ^{o}C and on the shelf at room temperature (28$\underline{+}$2 ^{o}C). Proximate composition, physical and physicochemical properties and RVA pasting properties were determined using the analytical methods earlier described in sections 3.2.2 and 3.2.3. Uncooked macaroni hardness (or breaking force), microbiological evaluation, mineral assay, cooking characteristics and sensory evaluations were carried out as outlined below.

3.3.2.1 Determination of pH of macaroni noodle dough

Thermo Orion pH meter (model 410) was standardized with standard buffer solution 4.0 and 7.0 at 25 ^{o}C. About 20 g of noodle dough was weighed and homogenized in 100 mL distilled water in a centrifuge bottle. This was agitated on a wrist action shaker for 30 min and then centrifuged at 2,200 x g for 20 min. Supernatant was decanted and the pH measured by inserting the electrodes directly into the supernatant.

3.3.2.2 Determination of uncooked macaroni hardness

Macaroni noodle hardness was determined by measuring the force required to break uncooked (dried) macaroni piece (Yagci and Gogus, 2008) at three different points along its length using a Hardness tester (No 174886, Kiya Seisakusho Ltd., Tokyo, Japan). Test was carried out after 12 weeks of storage. Fifteen (15) representative pieces per sample was used for each determination.

3.3.2.3 Determination of microbial count of uncooked macaroni noodles

Noodles samples (dried) were ground, after 12 weeks of storage, using a sterile blender, and about 50 g analytical units were weighed out to determine aerobic plate count value and most probable number of coliforms. To this, 450 ml Butterfield's phosphate-buffered dilution water was added and blended for about 2 min. Dilutions of original homogenate were made promptly, using pipets that deliver required volume accurately. All decimal dilutions were prepared with 90 mL of sterile diluent and 10 mL of previous dilution. All dilutions were shaken vigorously 25 times and placed in appropriate media immediately. Procedure for analysis of frozen, chilled, precooked, or prepared foods was followed (APHA, 1984; AOAC, 1990).

Using separate sterile pipets, decimal dilutions of 10^{-2}, 10^{-3}, 10^{-4}, were prepared by transferring 10 mL of previous dilution to 90 mL of diluent. Sampling foaming was avoided. All dilutions were shaken 25 times in 30 cm (1 foot) arc within 7 s. 1 mL of each dilution was pipetted into separate dishes as duplicate, appropriately marked petri dishes. Dilution bottle are re-shaken 25 times in 30 cm arc within 7 s if it stands more than 3 min before it is pipetted into petri dish. To this, 12-15 mL plate count agar (cooled to 45 ± 1 ºC) was added to each plate within 15 min of original dilution. Agar and dilution water control plates were poured for each series of samples. Sample dilutions and agar medium were thoroughly mixed uniformly by alternate rotation and back-and-forth motion of plates on flat level surface. Agar was allowed to solidify and solidified petri dishes were inverted, and incubated promptly for 48 ± 2 h at 35 ºC.

The Aerobic Plate Count (APC) was calculated as follows:

$$N = \frac{\sum c}{[(1 \times n_1) + (0.1 \times n_2)] \times (d)} \qquad \text{..........................(3.16)}$$

where

N = Number of colonies per ml or g of product
c = Sum of all colonies on all plates counted
n_1 = Number of plates in first dilution counted
n_2 = Number of plates in second dilution counted
d = Dilution from which the first counts were obtained

3.3.2.4 Determination of mineral profile of uncooked macaroni noodles

This was determined using Inductively-Coupled Plasma Atomic Emission Spectrometer (ICPAES) at IITA analytical laboratory (Questron technologies corp. TL 6000). About 20 g of cassava-semolina macaroni noodles was fine-milled into powder using a well cleaned, Capino coffee blender; a Capressa stainless steel burr grinder.

About 0.4-0.5 g of sample was weighed into a 50 mL digestion tube and digested with 2mL of conc. redistilled nitric acid (HNO_3), and left overnight on a digestion block at 120 ^oC. As the liquid dried off, conc nitric acid was continually added until the sample no longer gave off reddish – brown fumes and the solution became clear. A solution of 50/50 (v/v) nitric acid and perchloric acid was then added, and temperature increased to 180 ^oC – 220 ^oC. This was heated to dryness, leaving a white ash-like residue, which was cooled and re-dissolved with 1ml of conc. hydrochloric acid (HCl) and 10 mL of 5% nitric acid, vortexed and transferred into 15 mL centrifuge tubes for analysis. Sample ash solution was injected into the ICPAES to determine the mineral content. Mineral content was calculated as shown below:

$$\text{Mineral content (mg/kg)} = \frac{\text{Conc. (ppm) x D.F.}}{\text{Sample weight (g)}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.17)$$

where D.F = dilution factor = 11

3.3.2.5 Cooking characteristics of dried cassava-semolina macaroni noodles

The cooking procedures adopted by Kim *et al*. (1996) for starch noodles; and that described by Yoenyongbuddhagal and Noomhorm (2002) for rice flour vermicelli was used after appropriate modification. Ten grammes (10 g) of macaroni noodles was soaked in 300 mL of potable water for 5 min; drained and then cooked in 200 mL boiling water. Optimum ***cooking time*** was determined as described by Kim and Wiesenborn (1996) by removing one piece of macaroni each at 30 sec interval, during cooking. This was subjectively examined for opaqueness at the noodle center.

Optimum cooking time is that at which the opaque center becomes transparent, having been hydrated through cooking. Cooked macaroni noodles were drained and rinsed with 30-50 mL tap water.

Cooked weight was obtained by weighing the wet mass after draining for about 2.5 min in a Buchner funnel.

Cooking loss was determined according to the method described by Mestres *et al*. (1988). The combined water (cooking and rinsing water), was centrifuged at 2,300 rpm for 10 min. The supernatant was decanted into a pre-weighed moisture can and dried in hot air oven at 105 ^{o}C to constant weight while the sediment (in the pre-weighed centrifuge tube) was dried at 60-70 ^{o}C. Solid loss was calculated from the weight of sediment, while soluble loss was determined from the dried weight of the supernatant and both were expressed as percentages of original macaroni noodle weight. Total cooking loss was calculated as the sum of solid and soluble losses.

Water absorption index in this context, was obtained from the percentage of weight increase in the cooked macaroni sample, and compared with the weight of the dry starting sample (Yoenyongbuddhagal and Noomhorm 2002).

3.3.2.6 Sensory evaluation of dried noodles

Cassava macaroni noodles was evaluated for sensory attributes of colour, appearance, firmness, stickiness, chewiness, elasticity, taste and overall acceptability using the method outlined by Larmond (1970), and adopted by Kim and Wiesenborn (1996) for starch noodles. Fifteen experienced sensory evaluators who were regular consumers of pasta products were selected from the staff and graduate students of Crop Utilization Unit of IITA, Ibadan where this study was conducted. These chosen panelists were trained in two training sessions over a 2-week period. They were informed about the purpose of the research, the product concept and terminologies of chosen sensory attributes were defined as they related to starch noodles (refer to Appendix 3.2). The essence of ranking as an additional tool was explained.

Preliminary product selection was made in batches or sets, for each level of cassava incorporation at the three hydration levels in order to reduce the number of samples to be presented (Larmond, 1970; Yagci and Gogus, 2008). Their preference for colour, appearance, firmness, stickiness, chewiness, elasticity, taste and overall acceptability was indicated on a 9- point hedonic scale in which 9 represented ‘like extremely' and 1, ''dislike extremely'' (Appendix 4.9) Panelists were asked to also rank each set of sample 1st, 2nd and 3rd. Evaluations were conducted in mid-morning and the samples were coded with 3-digit random numbers (Kim and Wiesenborn, 1996). Based on the responses obtained, representative preferred samples were selected from each set (i.e. at 45 or 50 or 55% hydration level).

A pool of six (6) selected representative samples from each set was thereafter compared with the commercial macaroni noodle to determine the closest in terms of the tested sensory attributes. Commercial macaroni (Golden Penny brand), was purchased from open market and used as standard or reference sample 'R' (i.e. made from 100% durum wheat semolina). Panelists were asked to score each representative sample of cassava substitution levels in comparison with 'R' on a scale of 5; where 5 represented "greatly superior to R", 3 represented "equal to R" and 1, "greatly inferior to R" (Appendix 4.10). Two (2) sensory trials were performed at 24 hr intervals using the same noodle samples. No sauce was provided for panelists. Sensory evaluation was conducted in a calm atmosphere without interference during test in a designated room, partitioned and well lit (Appendix 4.11).

3.4 Statistical analyses

All analyses were carried out in duplicate, unless otherwise stated. Results obtained for the flour samples were analyzed, means and standard deviation were obtained as data was subjected to one-way analysis of variance (ANOVA) using the SAS 9.2 statistical package. Mean comparison and separation was done using LSD ($p<0.05$).

For the developed macaroni noodles, the experimental design was a randomized complete block with a factorial arrangement of cassava starch incorporation (6) and hydration level during macaroni extrusion (3). The General Linear Model (GLM) procedure of the Statistical Analysis System, version 9.2 (SAS Institute Inc.,) was used for data analysis. Fischer's least significance difference (LSD) test was used to compare and separate means at 5% significance level. Pearson's correlation coefficients were calculated for Physicochemical properties (RVA and cooking) of cassava-semolina macaroni noodles, using Statistical Analysis System SAS-9.2 version

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Physical properties of cassava starch, durum wheat semolina and their blends

4.1.1 Particle size distribution of cassava starch and durum wheat semolina

Durum semolina used in this study (as is used in the pasta factory) was coarse and of medium granulation (Figure 4.1) and the main mass fraction was found to be between 250 and 300 µm (38.8 %). Petitot *et al*. (2010) characterised durum wheat semolina as having a monomodal particle size distribution (single peak at 340 lm) and composing mostly of particles in the 160–1000 lm range. On the other hand, cassava starch used in this study had a finer particle size distribution (on milling) compared to wheat semolina, with the main mass fraction found to be <150 µm (80.6%). Particle size distribution of milled flours affect the rate of hydration during pasta processing, as very fine (<180 µm) particle sized flours have greater tendency of absorbing more water during hydration (Dalbon *et al*., 1996). Hou and Kruk (1998) reported that large particle flours required a longer time for water to incorporate and tend to form larger dough lumps. Optimum dough mixing would thus require fine and evenly distributed particle size flours.

Tian *et al* (1991) suggested that small granules have higher solubility and hence enhanced water absorption capacity, which have positive implications for functionality of flour during processing. Large granules would be insufficiently hydrated and thus produce white spots on pasta surface. The granules of cassava (3-28 µm) and wheat starches (3-34 µm) are of intermediate sizes (Table 2.9). Hence, as reported by Hoseney (1994), finer flour particle size—with adequate water absorption—can create more cohesion in most baking systems. While the granules of cassava starch are oval truncate shaped with smooth surfaces, those of wheat are mostly round lenticular. The flours used in this study were easily hydrated and cohesive doughs were obtained prior to extrusion.

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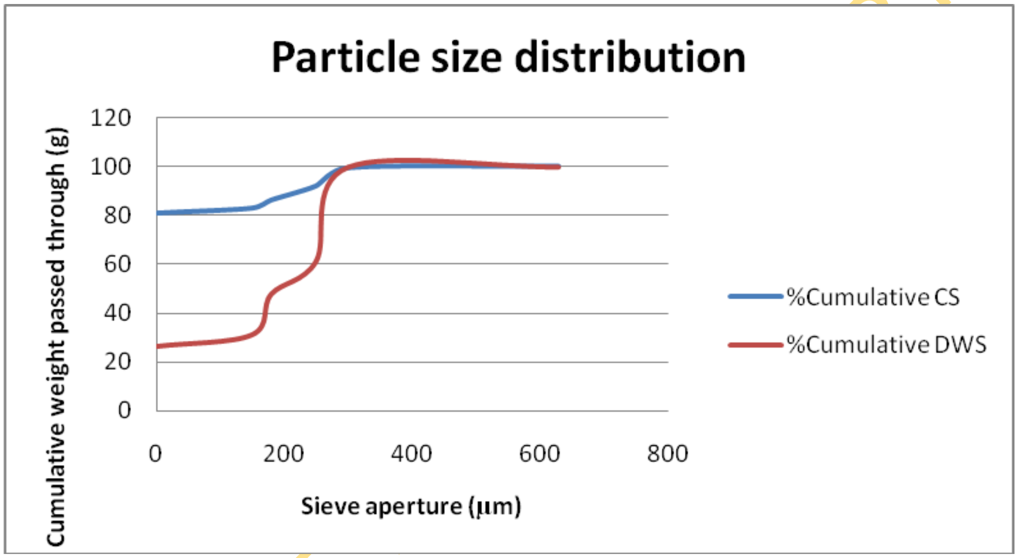


Figure 4.1 Particle size distribution of durum wheat semolina and cassava starch

4.1.2 Bulk density and starch damage of cassava starch and durum wheat semolina

Bulk density, starch damage and absorption rate ranged from 0.39 - 0.94 g/cm^3, 3.25 - 7.17%, and 91.44 - 97.12% in respective order for wheat semolina and its blend with cassava starch at 0 to 100% substitution levels (Table 4.1). A decline in absorption speed was however observed (67.0 to 24.0 sec) as wheat substitution increased.

Bulk density of cassava starch (0.94 g/cm^3) more than doubled that of wheat semolina (0.39 g/cm^3), an indication that the former has a greater tendency of settling or compacting in feeders and hoppers during large-scale production. Dubat (2004) proffered a solution in which the feeder/hopper is vibrated or agitated to prevent the formation of a stable arch inside the feeder (bridging) or sticking of the starch to the walls of the feeder (tunneling). Cassava-wheat blends however had bulk densities varying from 0.79 to 0.85 g/cm^3.

Increase in starch damage as cassava starch incorporation increased may account for the increases observed in water absorption capacities, as damaged starch is able to absorb four to five times more water than intact starch (Milatovi and Mondelli, 1991). Level of starch damage has however been associated with increased stickiness of cooked pasta (Grant *et al*., 1993). Dubat (2004) studied the importance and impact of starch damage extensively and reported that damaged starch does not just absorb water (as compared to 0.4 by native starch), but also has much greater water retention capacity. Thus resulting in increased stickiness of dough and reduced cooking and eating qualities of noodle.

4.1.3 Colour of cassava starch, durum wheat semolina and their blends

Colour of flour blends showed increasing brightness (L*), reducing redness (a*), and reducing yellowness (b*) as white cassava starch was increasingly included in the amber coloured durum wheat semolina (Fig. 4.2). Flour samples were observed to be lighter and whiter as cassava concentration increased due to the increased dilution of the coloured pigments contained in durum wheat semolina. For breadmaking, where whiteness is desired, flour colour of color L * >90 is often required (Shelton, 2004).

Table 4.1 Bulk density and starch damage of cassava starch, durum wheat semolina and their blends

Flour containing	Bulk density (g/cm^3)	Starch damage		
		AACC (%)	Absorption rate (%)	Absorption speed (secs.)
100% durum wheat semolina	0.39^b	3.25^f	91.44^f	67.0^a
20% Cassava starch	0.79^{ab}	4.50^e	93.51^e	52.0^b
30% Cassava starch	0.80^{ab}	5.53^d	95.01^d	39.01^c
50% Cassava starch	0.83^{ab}	6.34^c	96.09^c	30.0^d
70% Cassava starch	0.85^{ab}	6.91^b	96.80^b	28.0^d
100% Cassava starch	0.94^a	7.17^a	97.12^a	24.0^e
LSD	0.48	0.11	0.26	2.83

Values are averages of two replicates. Same superscripts in each row indicate no significant difference at $P > 0.05$

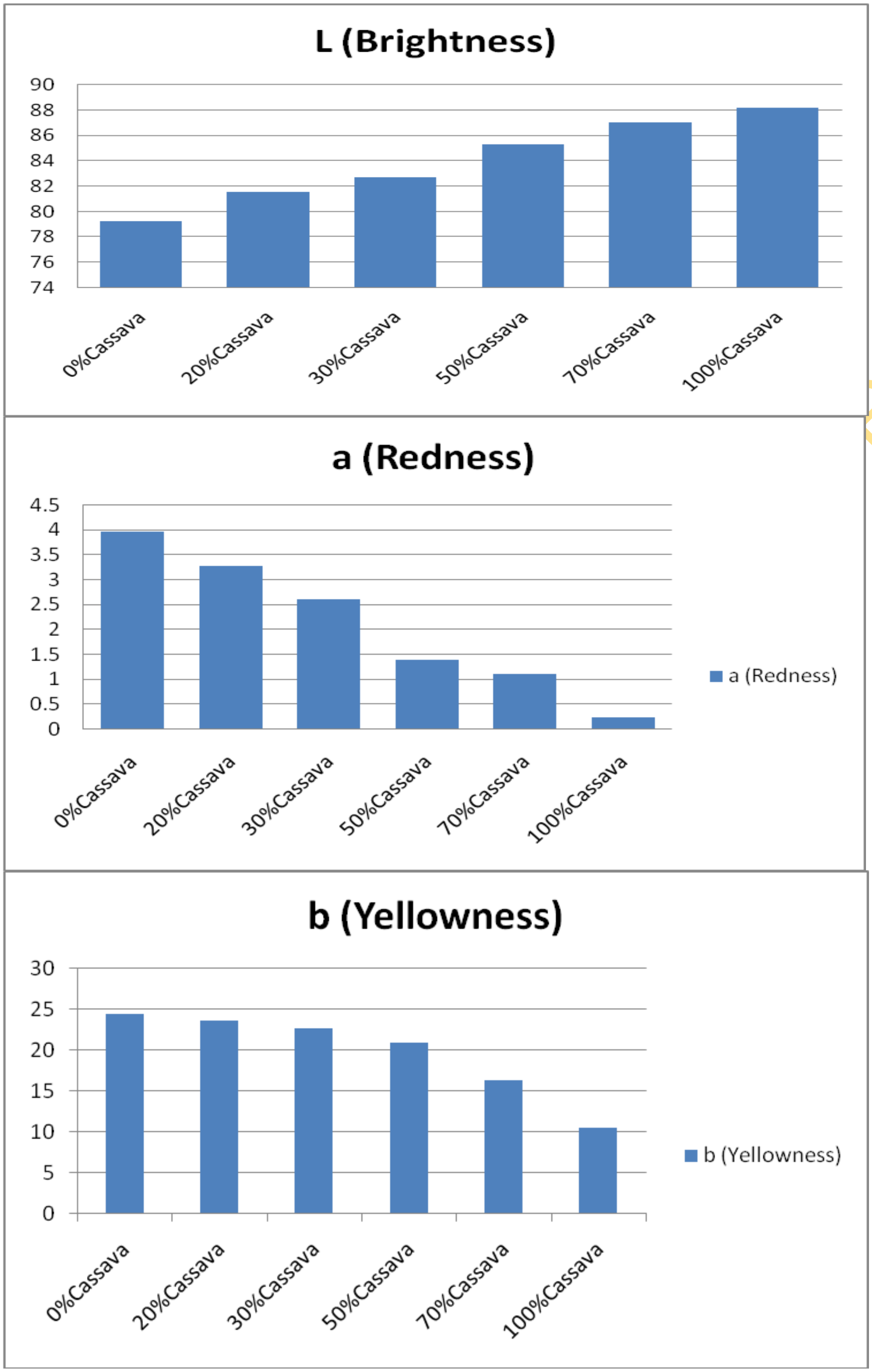


Figure 4.2. Brightness, Redness &Yellowness of flour samples.

Pasta on the other hand is preferred to be bright-yellow in colour (Debbouz *et al.*, 1995). Lower ash content of cassava starch may account for this increased brightness in comparison with wheat semolina. This, by inference is similar to the observation made by Petitot *et al* (2010) when durum wheat semolina was fortified with legume flour of higher ash content than wheat semolina. The reduction in yellowness (b*) was not as pronounced as the reduction in redness (a*value) as cassava starch concentration increased, probably because of the higher concentration of the yellow pigment contained in durum wheat endosperm and its high ash content (0.85) relative to cassava starch (0.12).

4.2 Chemical and physicochemical properties of cassava starch, durum wheat semolina and their blends

The age, variety and location of cassava roots reportedly influence the physicochemical and functional properties of its starch such as the cassava starch yield, solubility, swelling power and water-binding capacity.

4.2.1 Proximate composition of cassava starch, durum wheat semolina and their blends

As shown in Table 4.2, moisture content, fat, ash and protein contents ranged from 10.38-11.58%, 0.95-4.41%, 0.12-0.83%, and 0.75-12.31% respectively as level of wheat substitution with cassava starch increased from 0 to 100%. Moisture variation is probably due to the handling procedure from point of production. High moisture level of flour predisposes it to caking and spoilage, and hence reduced shelf-life on storage. Values are however within the acceptable range (12-14%) of moisture content for cereal flour storage (Hayma, 2003). Values obtained were however within the range reported for moisture (11.4-13.5%), ash (0.35-0.41%), and protein (7.96-8.95%) by Toyokawa *et al* (1999) for wheat flours used for noodle production. The low protein and ash values obtained for cassava starch was expected since cassava is lower in protein (0.6%) and ash (0.9%) than wheat. On the other hand, wheat semolina had a protein level of 12.31% and an ash content of 0.83%, being as a result of its proteinous

Table 4.2. Proximate composition of cassava starch, durum wheat semolina and their blends

Flour containing	Moisture (%)	Fat (%)	Protein (%)	Ash (%)	Carbohydrate (%)	Energy* (Kcal/100g)
100% Durum wheat semolina	11.58^a	4.41^a	12.31^a	0.83^a	70.87^f	372.41^a
20% Cassava starch	11.53^a	2.98^b	9.94^b	0.73^b	74.82^e	365.86^b
30% Cassava starch	11.48^a	2.89^c	8.54^c	0.67^c	76.42^d	365.85^b
50% Cassava starch	11.27^b	2.50^d	6.21^d	0.56^d	79.46^c	365.18^c
70% Cassava starch	11.34^b	2.16^e	4.62^e	0.36^e	81.52^b	364.00^d
100% Cassava starch	10.38^c	0.95^f	0.75^f	0.12^f	87.80^a	362.75^e
LSD	0.115	0.038	0.151	0.0168	0.148	0.239

Values are means of two replicates. Values with same superscripts along the column are not significantly different at $P<0.0001$

*Values calculated using Atwater's factors gluten matrix (Manthey and Schorno, 2002). The concentration of gluten, the major constituent of wheat protein responsible for its visco-elastic properties, was being increasingly reduced as cassava starch was added to wheat. Flour blends showed a 6.61% increase in carbohydrate content at 30% level of substitution with cassava starch. This is because cassava is a starchy staple and a good source of carbohydrate (Lebot, 2009). The higher ash content of wheat is probably an indication of the nutrient and minerals it contains

4.2.2 Physicochemical properties of cassava starch, durum wheat semolina and their blends

Amylose content, maltose figure, falling number, gluten and cyanide contents of flour samples ranged from 19.49-28.19%, 96-244 mg/10g, 260-702 sec., 0-27.2% and 0-0.05% respectively (Table 4.3). Obtained amylose values are similar to those reported by Kim *et al*. (1996) for Mainechip potato starch (22.7%) and the commercial food grade potato starch (20.0%) obtained from Avebe Company, North Dakota, sold for noodle making. These values are also in agreement with those reported by Satin (2009) for cassava (17%) and wheat (26%) starch species (Table 2.9). The low amylose content of cassava and its blends have been associated with good textured white salted noodles (Toyokawa *et al*. 1989), and thus suggest that noodles made from the blends would probably exhibit some good textural qualities. The amylose: amylopectin ratio was however maintained at 0.3 - 0.4 for all the flour samples.

As shown in Table 4.3, maltose figure (96 mg/10g) and falling number (260) of cassava starch were lower than that of wheat semolina (244 mg/10g and 702). There was however a 12.7% reduction in maltose figure and a 29.1% reduction in falling number at 20% substitution of wheat semolina with cassava starch. A very moderate alpha-amylase activity in TMS 30572 cassava starch is thus indicated. Ding and Zeng (1991), when listing processing qualities required of flours for making noodles, noted that a falling number >200seconds, among other parameters, would be ideal. This suggests that noodles developed with these flour samples would probably exhibit some acceptable characteristics. However, based on baking experience in the mills, Anonymous (2009) classified a falling number value of 350 or greater as an indication of low enzyme

Table 4.3 Physicochemical properties of cassava starch, durum wheat semolina and their blends

Flour containing	Sugar (%)	Starch (%)	%Starch as Amylose	Maltose Figure (mg/10g)	Falling Number (seconds)	Cyanide (ppm)	Gluten	Bulk density (g/cm^3)
100% durum wheat semolina	1.77^{bc}	60.56^{f}	28.19^{a}	244.0^{e}	702.0^{a}	0.00^{c}	27.2^{a}	0.39^{b}
20% Cassava starch	2.19^{a}	63.32^{e}	24.31^{b}	213.0^{d}	498.0^{b}	0.02^{b}	23.7^{b}	0.79^{ab}
30% Cassava starch	2.16^{a}	71.31^{d}	24.40^{b}	182.5^{c}	483.5^{bc}	0.02^{b}	18.5^{c}	0.83^{ab}
50% Cassava starch	1.61^{c}	75.31^{c}	22.04^{c}	177.5^{b}	430.0^{cd}	0.02^{b}	10.7^{d}	0.85^{ab}
70% Cassava starch	2.14^{ab}	80.31^{b}	19.92^{d}	140.5^{a}	410.0^{d}	0.02^{b}	1.20^{e}	0.94^{a}
100% Cassava starch	1.50^{c}	84.50^{a}	19.49^{d}	96.0^{f}	260.0^{e}	0.05^{a}	0.00^{f}	0.80^{ab}
LSD	0.39	1.48	0.96	5.04	55.28	0	0.97	0.48

Values are means of two replicates. Values with same superscripts along the column are not significantly different at $P>0.05$
ppm=parts per million

activity, while values below 200, an indication of high level of enzyme activity. Many North American and Japanese manufacturers demand a durum wheat falling number in excess of 300 sec for the manufacture of premium pasta products, which would suggest that 100% substitution with cassava starch (FN=260) would not yield acceptable noodles.

Gluten content decreased as levels of wheat substitution increased, indicating increased dilution of its gluten-matrix (Table 4.3). On the other hand, starch content in flour samples increased with increasing cassava incorporation. The efficacy of cyanide removal from cassava roots during starch preparation using FIIRO detoxification technique is shown in its level becoming reduced to 0.05 ppm from the reported 14.20 ppm for TMS30572 cassava cultivars (Dixon *et al*., 2010). The 99.6% reduction via processing, thus support the report of Dufour (2007) that there was a 93 to >99% reduction in cyanide level using similar processing methods (Table 2.8).

4.2.3 Swelling power and water binding properties of cassava starch, durum wheat semolina and their blends

Swelling power, solubility, water absorption capacity and water binding capacity of flour samples ranged from 7.80-9.01%, 2.16-4.36%, 92.9-164.65%, 69.5-147.48% respectively (Table 4.4). There was a gradual decline in swelling power (from 7.80 to 7.41 g/g) of wheat semolina with increasing cassava starch incorporation up to 30%, probably because at this temperature (80 ^{o}C), swelling of wheat starch was restricted due to the formation of amylose-lipid complexes in the granules (Noranizan *et al*., 2010). The amylose-lipid complex inhibits dispersion of the starch granules, thus suggesting that there were limited means to promote leaching of soluble materials from the intact granules until wheat starch concentration reduced to 50% (or cassava starch concentration increased to 50%) and beyond. At 50% level of wheat substitution, swelling power increased from 7.89 g/g to 8.30 g/g at 70% and 9.01 g/g at 100%, indicating the relative fragility of the cassava granules (Charles *et al*., 2005). This is probably an indication that the starch granules, having been substantially degraded after undergoing maximum swelling around their respective gelatinization temperature (50.18/50.25 ^{o}C; Table 4.5), now completely leach out both the amylose and amylopectin contents (Noranizan *et al*., 2010). Value obtained for swelling power (9.01 g/g) of 100%

Table 4.4 Swelling power and water binding capacity of cassava starch, durum wheat semolina and their blends

Flour containing	Swelling Power (g/g)	Solubility (%)	Water Absorption Capacity (%)	Water Binding Capacity (%)
100% durum wheat semolina	7.80^{c}	4.36^{a}	92.9^{e}	69.5^{f}
20% Cassava starch	7.51^{d}	3.86^{b}	97.02^{d}	90.58^{e}
30% Cassava starch	7.41^{d}	3.77^{c}	98.56^{d}	94.81^{d}
50% Cassava starch	7.89^{c}	3.81^{bc}	103.16^{c}	105.69^{c}
70% Cassava starch	8.30^{b}	3.36^{d}	126.56^{b}	117.85^{b}
100% Cassava starch	9.01^{a}	2.16^{e}	164.65^{a}	147.48^{a}
LSD	0.18	0.06	2.41	2.17

Values are averages of two replicates. Same superscripts in each column indicate no significant difference at $P>0.05$

cassava starch was comparable to that reported by Daramola and Osanyinlusi (2006), for native cassava starch (8.9 g/g), though the solubility of cassava starch in this study (2.16%) was lower than they reported (3.1%).

The pattern observed in swelling power from 0 to 30% wheat substitution with cassava starch was similarly obtained for starch solubility. Solubility which increased from 3.77% to 3.81 at 50% substitution thereafter declined with further incorporation of cassava starch. A similar trend was observed in earlier reports (Kim *et al*., 1996) and was attributed to the low fat content and the weak internal organization within root and tuber starches (Wiesenborn *et al*., 1994; Kim *et al*., 1995 and Kim *et al*., 1996), thus explaining why water absorption capacities and water binding capacities increased with increasing starch incorporation into noodle flour blends (Table 4.4). However, beyond 50% substitution with cassava starch, solubility reduced, giving a minimum of 2.16% at 100% wheat substitution.

4.2.4 Pasting properties of cassava starch, durum wheat semolina and their blends

Peak viscosity, holding strength, breakdown, final viscosity, setback value, peak time and pasting temperature ranged from 96.33-364.34 RVU, 70.84-153.35 RVU, 25.5-210.84 RVU, 127.67-215.96 RVU, 49.71-72.29 RVU, 4.01-5.32 min., 50.18-50.25 ^{o}C respectively (Table 4.5). There was little or no variation in the pasting temperatures of cassava starch (50.25 ^{o}C) and durum wheat semolina (50.18 ^{o}C), probably an indication of some similarity between the two starches, despite being from root and tuber and cereal respectively. In contrast to this, higher values of pasting temperature (63.95- 67.10 °C) were reported by Boakye (2001) for cassava starch obtained from four cassava cultivars harvested in Ghana. Also, Kim *et al.* (1996) studied the suitability of edible bean and potato starches for making starch noodle and obtained higher values of gelatinization temperature for potato starches (62.7-67.8 ^{o}C). However, information from science-based encyclopedia noted that gelatinization temperature of starches is affected by the granular size, moisture content, protein and sugar contents, the presence of fat and the degree of crosslinking within the amylopectin polymer (Anonymous, 2012). Hence, these observed variations could be attributed to a combination of factors. Peak viscosity increased as

Table 4.5 Pasting properties of flour samples used for macaroni noodle production

Flour containing	Peak Viscosity (RVU)	Holding Strength (RVU)	Break down (RVU)	Final Viscosity (RVU)	Setback value (RVU)	Peak Time (mins.)	Pasting Temperature (^{o}C)
100% durum wheat semolina	96.33^{d}	70.84^{d}	25.5^{d}	150.13^{b}	72.29^{a}	5.32^{a}	50.18^{a}
20% Cassava starch	124.09^{c}	81.00^{bc}	43.0^{c}	144.00^{b}	63.00^{b}	5.25^{a}	50.18^{a}
30% Cassava starch	132.04^{c}	83.55^{bc}	48.5^{c}	141.09^{b}	57.54^{c}	5.01^{b}	50.20^{a}
50% Cassava starch	155.17^{b}	77.96^{c}	77.2^{b}	127.67^{c}	49.71^{d}	4.05^{c}	50.23^{a}
70% Cassava starch	134.17^{c}	86.13^{b}	48.04^{c}	144.25^{b}	58.13^{c}	5.00^{b}	50.23^{a}
100% Cassava starch	364.34^{a}	153.5^{a}	210.84^{a}	215.96^{a}	62.46^{b}	4.01^{c}	50.25^{a}
LSD	14.27	7.08	9.29	9.87	3.65	0.18	0.22

Values are means of two replicates. Values with same superscripts along the column are not significantly different at P>0.05

RVU=Rapid Viscosity Unit

cassava inclusion increased, reached a peak at 50% substitution and then reduced at 70% substitution with cassava starch. The rapidly attained high peak viscosity value (155.17 RVU) at 50% cassava starch inclusion is probably an indication that majority of the starch granules had become swollen at 4 minutes. Subsequently, the granules rupture and the more soluble amylose leaches out into solution, leading to a final viscosity value of 127.67 RVU. The extraordinarily high peak viscosity of 100% cassava starch (364.34 RVU) could be attributed to its weak granular structure (Nwokocha *et al., 2009*). The low amylose content of cassava starch (19.49%, Table 4.3), indicating a corresponding high content of amylopectin (80.51%) might be responsible for this observed peak viscosity, since starch swelling has been shown to be dependent on amylopectin content (Sasaki *et al*., 2000).

However, holding strength and breakdown viscosity which is a measure of paste stability, increased with increasing cassava starch inclusion up to 30 and 50% levels respectively. After this, there was a reduction in value probably indicating the acceptable limit to which cassava inclusion could be tolerated by wheat semolina in making a stable paste. Similar reduction in paste viscosity during holding period was observed by Kim *et al*. (1996) for potato starch for noodle production. This was attributed to the fragmentation of the starch granules and the hydrolysis of amylose chains by hydrogen ions (Kim *et al*., 1996). The farinogram curves obtained for the flour samples and their blends show (Fig. 4.3) greater instability when cassava inclusion was beyond 50%.

Mixing stability of flour samples are shown in the Farinogram curves (Fig. 4.3). At 0, 20, 30 and 50% substitution levels, doughs were stable, probably because durum wheat semolina had very high gluten content (27.2) and at 50% substitution with cassava starch, a residual gluten content of 10.7 was still able to hold forth the viscoelastic gluten network. The low gluten content at 70% (1.2) and 100% (0.0) substitution levels could be responsible for the lack of network formed. A similar unstable farinogram curve was observed by Gunathilake and Abeyrathne (2008) while incorporating coconut flour into noodle flour beyond 30%.

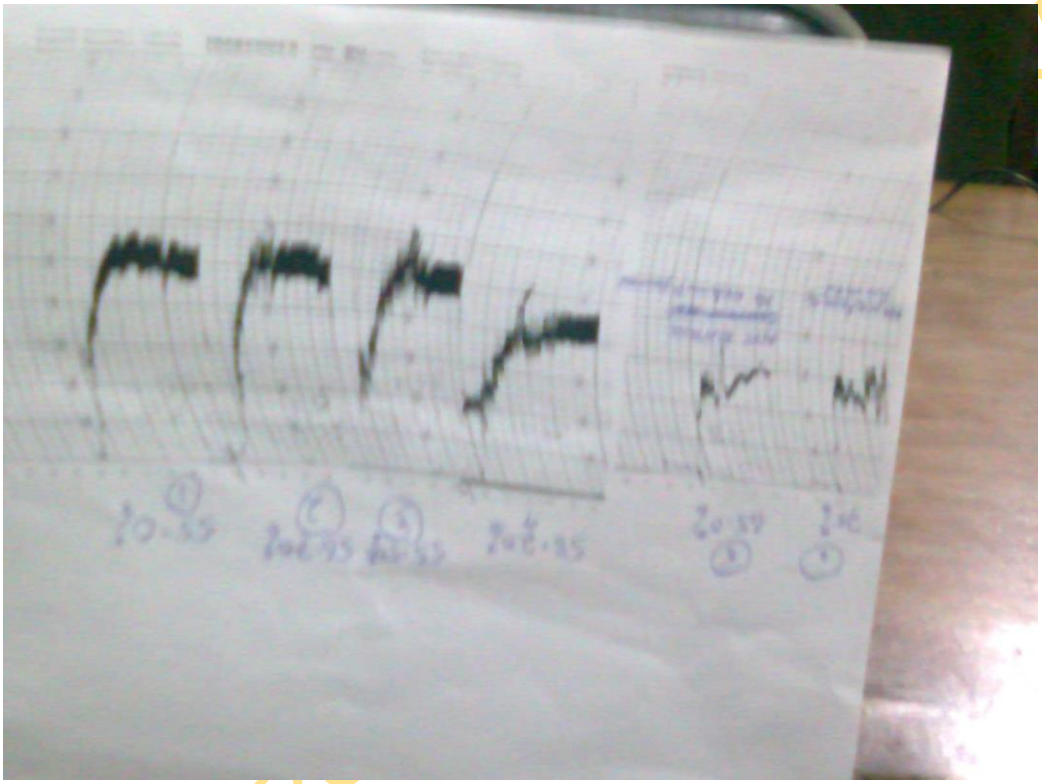


Figure 4.3 Farinogram curves at 0, 20,30,50,70 and 100% substitution of durum wheat semolina with cassava starch

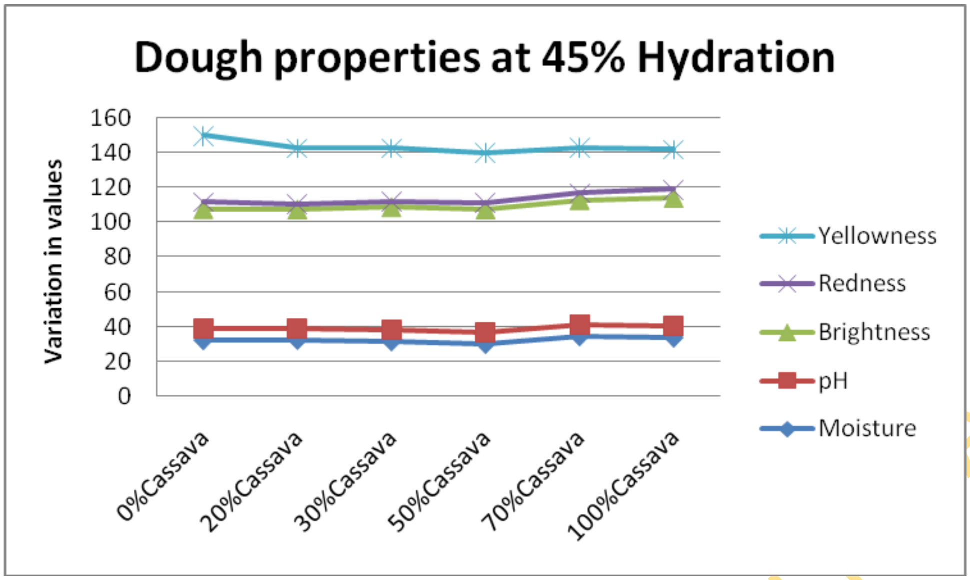
4.3 Effect of cassava starch incorporation and hydration level variation on dough and macaroni noodles properties

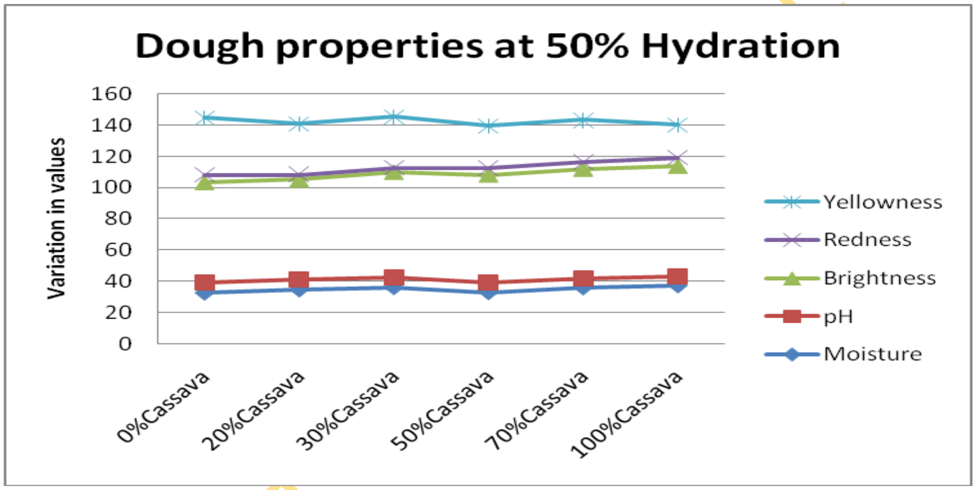
Doughs formed with durum wheat semolina and its blends with cassava starch were viscoelastic and malleable to touch. Hoseney and Rogers (1990) attributed this ability to the gluten protein's large molecular size and low charge density which appear to allow them to interact by both hydrogen and hydrophobic bonds.

4.3.1 Effect of cassava starch inclusion and hydration level variation on moisture content, pH and colour of macaroni noodle dough

Variation in moisture content, pH, and colour of macaroni noodle dough are presented graphically in Figure 4.4. Minimal variation in moisture content and pH for cassava-semolina macaroni noodle dough was observed at 45, 50 and 55% hydration levels. The moisture levels obtained were slightly higher than those reported by Manthey and Schorno (2002) for semolina and whole wheat doughs (32-33%) used for spaghetti production, and could be attributed to the inclusion of cassava starch which has high water absorption capacity. The pH obtained for all macaroni noodle doughs ranged from 5.6 – 6.8, a level associated with the alkali used in macaroni preparation. Similar pH was reported by Bajracharya *et al* (1999) for pasta dough sheet (5.6). Both cassava incorporation and hydration levels affected the moisture content, colour and pH significantly ($p<0.001$). There was minimal reduction in dough brightness and redness as hydration level increased, but an obvious increase with cassava starch inclusion. Yellowness reduced with increasing incorporation of cassava starch, due presumably to the increased dilution of the coloured pigments contained in durum wheat semolina.

Analysis of variance revealed that cassava starch incorporation and hydration level interaction was significant for dough moisture content, pH, redness and yellowness of dough colour; but not for dough brightness (Appendix 4.1).





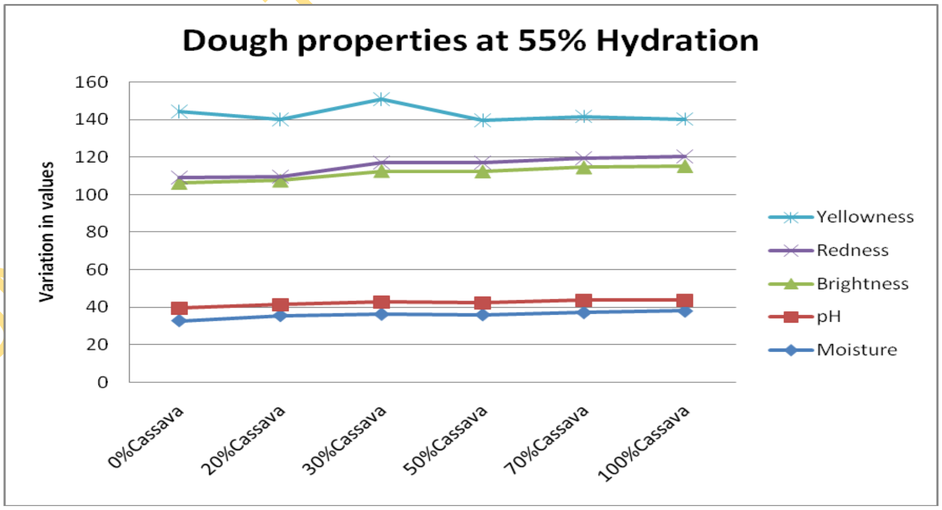


Figure 4.4 Effect of cassava starch inclusion and hydration level variation on moisture content, pH and colour of macaroni noodle dough

4.3.2 Proximate composition of cassava-semolina macaroni noodles

Protein, fat, ash, moisture, carbohydrate and energy contents of cassava-wheat semolina macaroni ranged from 6.09-15.68%, 4.51-6.09%, 1.49-2.17%, 5.25-10.19%, 65.87-82.66%, 381.01-395.59Kcal/100g respectively at 45% hydration level for 0 to 100% level of wheat substitution with cassava starch (Table 4.6). Moisture levels obtained (5.25-8.64%) were lower than that reported by Osorio-Diaz *et al* (2008) for durum wheat pasta (12.5%), but closer to that of macaroni (7.71%) reported by Herken *et al* (2007). On the other hand, the fat and ash contents obtained for cassava-based macaroni in this study (3.17-5.78%; 1.50-2.14%) were higher than those obtained by earlier workers (Herken *et al*., 2007; Osorio-Diaz *et al*., 2008), but comparable to the commercial macaroni analysed in this study (DWM). Protein content reported by Marconi *et al*. (1999) and Bergman *et al*. (1994) for durum wheat based pasta (10.7 and 16.02%) was comparable to that obtained for 0%, 20%, 30% and 50% wheat substitution with cassava starch, beyond which protein contents were lower (Table 4.6). Oh *et al* (1983) found that the protein content of flour influenced the chewiness of cooked noodles. On the other hand, macaroni had higher carbohydrate and energy values compared to those from wheat semolina, for the same reason that cassava is a good source of carbohydrate. Energy content was increased from 355.21 kcal/100g (commercial, from 100% wheat semolina) to 375.16-393.54 kcal/100g for macaroni noodles made from flour blends containing 20-70% cassava starch.

ANOVA revealed that wheat substitution with cassava starch and the hydration levels used had a significant effect on the moisture content, fat, and energy (P<0.0001, 0.001 and <0.0001 respectively); but not on ash, protein and carbohydrate (P= 0.09, 0.26 and 0.39 respectively). Cassava starch incorporation when singly considered, however, had very significant effect on all the proximate parameters (p<0.0001) while hydration level still had no significant effect on protein and ash contents (Appendix 4.2)

Table 4.6 Effect of substituting durum wheat semolina with cassava starch on proximate composition of cassava-semolina macaroni noodles made at three hydration levels

Level of cassava starch incorporation	Hydration level(%)	Protein (%)	Fat (%)	Ash (%)	Moisture (%)	CHO (%)	Energy (Kcal/100g)
100% Durum wheat semolina	45%	15.68^{a}	6.09^{a}	2.17^{ab}	10.19^{b}	76.07^{m}	421.75^{a}
	50%	15.56^{a}	5.30^{ed}	2.09^{bc}	9.52^{c}	77.06^{ml}	418.13^{cd}
	55%	15.70^{a}	4.91^{f}	2.18^{a}	9.71^{c}	77.22^{klm}	415.81^{f}
20% Cassava starch	45%	13.69^{b}	5.78^{b}	2.1^{abc}	8.24^{ef}	78.44^{jk}	420.48^{b}
	50%	13.68^{b}	5.14^{e}	2.07^{c}	8.35^{de}	79.11^{ij}	417.40^{ed}
	55%	15.20^{a}	4.47^{g}	2.14^{abc}	8.40^{de}	78.19^{jkl}	413.79^{gh}
30% Cassava starch	45%	12.31^{c}	5.50^{c}	1.91^{ed}	7.55^{hi}	80.29^{hi}	419.85^{b}
	50%	11.93^{c}	4.77^{f}	1.95^{d}	7.49^{i}	81.35^{h}	416.03^{f}
	55%	12.23^{c}	4.17^{hi}	2.06^{c}	7.84^{gh}	81.55^{gh}	412.63^{i}
50% Cassava starch	45%	10.15^{d}	5.38^{cd}	1.71^{h}	6.63^{j}	82.76^{fg}	420.07^{b}
	50%	10.43^{d}	4.30^{h}	1.73^{gh}	7.27^{i}	83.54^{ef}	414.58^{g}
	55%	10.20^{d}	3.74^{j}	1.71^{h}	7.49^{i}	84.36^{e}	411.84^{i}
70% Cassava starch	45%	8.33^{e}	5.15^{e}	1.81^{fg}	7.99^{fg}	84.71^{ed}	418.50^{c}
	50%	8.38^{e}	4.05^{i}	1.86^{def}	8.41^{de}	85.71^{cd}	412.80^{hi}
	55%	8.14^{e}	3.40^{k}	1.82^{ef}	8.64^{d}	86.64^{bc}	409.71^{j}
100% Cassava starch	45%	6.09^{f}	4.51^{g}	1.49^{i}	5.25^{l}	87.91^{b}	416.55^{ef}
	50%	5.07^{fg}	3.64^{j}	1.57^{i}	8.64^{l}	89.73^{a}	411.90^{i}
	55%	4.88^{g}	3.17^{l}	1.50^{i}	5.91^{k}	90.46^{a}	409.86^{j}
Commercial macaroni		12.36^{c}	2.41^{m}	1.02^{j}	13.19^{a}	84.21^{e}	407.98^{k}

Values are means of two replicates. Values with same superscripts along the column are not significantly different at P>0.05

4.3.3 Physical and physicochemical properties of cassava-semolina macaroni noodles

Ranges of 0.64-0.76 g/cm^3, 2.53-5.32 N, 15.91-21.96%, 1.51-5.17% and 59.41-89.73% were obtained for bulk density, break force, amylose, sugar and starch contents of macaroni at 45% hydration level (Table 4.7). Variations in bulk density were minimal, ranging from 0.64 to 0.81 g/cm^3 for the prepared cassava-semolina noodles, but less than that obtained for the commercial sample (0.89 g/cm^3). In comparison with the values obtained for the flour samples and their blends (Table 4.1), there was an observed increase which could be due to increased cohesive forces developed during hydration of the protein and subsequent processing.

The breaking strength of dried macaroni was analyzed six weeks after production (Table 4.7). Breaking force varied between 2.07 N, for composite macaroni noodles containing 70% cassava starch at 55% hydration, and 4.99 N, for composite macaroni noodles containing 20% cassava starch at 45% hydration. Macaroni noodles made from 100% cassava starch had the least break force (1.23 N) while those prepared from 100% durum wheat semolina had much higher break force (6.15 N). Zweifel (2001) described the breaking strength (or breaking force) of pasta as a measure of its homogeneity and the density and continuity of the protein network which gives pasta its cohesiveness. Thus, protein content of flour used has a positive correlation with noodle hardness and a negative correlation with noodle brightness (Hou and Kruk, 1998). The highest break force obtained for commercial macaroni purchased from the open market (8.44 N) thus indicate a high level of homogeneity and cohesiveness. Kratzer *et al*., 2007 reported a breaking strength of 3 N for durum wheat spaghetti produced in a single-screw pasta extruder and higher values of 3.2-3.9 N for samples produced in a twin-screw extruder, probably due to a higher structural homogeneity thus attained. Hence, it could be deduced that extruder used in pasta production exert some impact on its ability to resist breakage. ANOVA revealed (Appendix 4.3) that both factors of the experiment, cassava inclusion and hydration level, had significant effect on breaking force of macaroni samples ($p<0.01\%$). Some earlier authors (Dexter and Matsuo, 1979; Morrison and Azudin, 1987; Toyokawa *et al*., 1989) considered amylose content to be an important factor affecting cooked noodle hardness. In this study, no significant correlation was found between

Table 4.7 Effect of substituting durum wheat semolina with cassava starch on physical and physico-chemical properties of cassava-semolina macaroni noodles made at three hydration levels

Level of cassava starch incorporation	Hydration Level (%)	Bulk density (g/cc)	Break Force (N)	Brightness (L)	Redness (a)	Yellowness (b)	Amylose (%)	Sugar (%)	Starch (%)
100% Durum wheat semolina	45%	0.64^{ef}	5.32^{c}	64.89^{a}	6.94^{kl}	49.44^{a}	15.91^{e}	5.17^{abcd}	76.84^{bcd}
	50%	0.81^{ab}	6.15^{b}	44.97^{fgh}	8.96^{cde}	48.81^{a}	18.10^{de}	6.12^{ab}	66.97^{cde}
	55%	0.66^{def}	4.13^{ef}	62.92^{ab}	9.29^{abcd}	47.96^{a}	18.05^{de}	4.54^{abcde}	91.82^{a}
20% Cassava starch	45%	0.65^{def}	4.12^{ef}	59.09^{b}	8.57^{defg}	32.17^{b}	18.05^{de}	2.90^{defg}	78.16^{bc}
	50%	0.65^{def}	4.99^{cd}	59.66^{b}	8.87^{cdef}	30.30^{c}	15.72^{e}	5.89^{ab}	81.68^{ab}
	55%	0.70^{bcdef}	4.34^{de}	53.56^{cd}	8.99^{bcde}	24.70^{ef}	20.23^{bcd}	4.94^{abcd}	68.77^{cde}
30% Cassava starch	45%	0.76^{bcde}	3.50^{fg}	54.27^{c}	9.50^{abc}	25.47^{e}	21.40^{abc}	4.37^{abcde}	65.40^{cde}
	50%	0.81^{abc}	5.06^{cd}	54.06^{cd}	8.10^{fghi}	27.86^{d}	20.23^{bcd}	4.25^{abcde}	66.03^{cde}
	55%	0.81^{abc}	2.61^{h}	52.84^{cd}	7.20^{jk}	28.97^{cd}	22.14^{abc}	5.49^{abc}	67.78^{cde}
50% Cassava starch	45%	0.69^{cdef}	3.68^{ef}	51.23^{cde}	9.57^{abc}	23.50^{fg}	22.79^{ab}	5.69^{abc}	89.73^{ab}
	50%	0.67^{def}	2.83^{gh}	47.47^{ef}	7.94^{ghij}	22.27^{gh}	23.49^{a}	3.49^{cdefg}	63.94^{e}
	55%	0.66^{def}	2.30^{h}	49.80^{de}	6.35^{lm}	20.88^{hi}	18.09^{de}	2.49^{efg}	62.78^{e}
70% Cassava starch	45%	0.76^{bcde}	2.57^{h}	47.13^{efg}	9.76^{ab}	20.88^{hi}	20.10^{cd}	6.17^{a}	61.90^{e}
	50%	0.64^{f}	2.36^{h}	42.94^{gh}	8.41^{efgh}	20.74^{hi}	21.54^{abc}	4.01^{abcdef}	59.97^{e}
	55%	0.68^{def}	2.07^{h}	42.63^{h}	7.70^{hijk}	19.87^{ij}	23.54^{a}	4.06^{abcdef}	67.97^{cde}
100% Cassava starch	45%	0.76^{bcd}	2.53^{h}	42.98^{gh}	9.90^{a}	20.04^{ij}	21.96^{abc}	1.51^{a}	59.41^{e}
	50%	0.76^{bcd}	2.23^{h}	41.22^{hi}	7.49^{ijk}	18.45^{jk}	16.75^{e}	1.87^{fg}	64.42^{de}
	55%	0.70^{bcdef}	1.23^{i}	38.11^{i}	5.75^{m}	16.82^{k}	21.26^{abc}	4.19^{abcdef}	57.25^{e}
Commercial macaroni		0.89^{a}	8.44^{a}	ND	ND	ND	21.86^{abc}	3.76^{bcdefg}	58.07^{e}

Values are means of two replicates. Values with same superscripts along the column are not significantly different at $P>0.05$

N is Newton, for breaking force ; ND is not determined

L,a,b are colour readings for brightness, redness & yellowness respectively amylose content and breaking force (r= - 0.27) of uncooked macaroni noodles (Appendix 4.7). Amylose content increased from 15.91 to 22.79% as cassava incorporation increased from 0 to 50% at 45% hydration (Table 4.7). Beyond 50% i.e. at 70% cassava inclusion, amylose content dropped significantly to 20.10%. The commercial durum wheat macaroni had an amylose content of 21.86%. Kim and Wiesenborn (1996) studied the suitability of potato starch and edible bean starches for making starch noodles, with both low and high amylose contents (ranging from 20.0 to 37.8%). Results obtained made them suggest that a threshold of amylose content is sufficient with respect to spaghetti cooking quality, thus indicating that other starch properties would probably be more important than amylose content. Amylose level in this study showed positive correlation to water absorption index (r = 0.56), and swelling volume (r = 0.47). Breaking force on the other hand showed a significant correlation to optimum cooking time (r = 0.73) and holding strength (r = - 0.51) at P<0.05. This showed direct variation of breaking force with optimum cooking time, while the reverse is the case for holding strength.

Starch concentration, as expected, were higher in cassava noodles as level of cassava starch incorporation increased. Analysis of variance (Appendix 4.3) revealed that the interaction of the cassava incorporation and hydration level had significant effect on most of the physical and physicochemical parameters studied, i.e: uncooked noodle-breaking force, brightness and yellowness of colour, amylose, sugar and starch contents ($P < 0.05$); but not for bulk density ($P = 0.10$) and redness of colour ($P = 0.6$).

4.3.4 Pasting properties of cassava-semolina macaroni noodles

Peak viscosity, holding strength, breakdown, final viscosity, setback, peak time and pasting temperature ranged from 27.55-145.08 RVU,22.84-100.13 RVU, 4.71-44.96 RVU, 52.88-169.29 RVU, 30.04-69.17 RVU, 4.01-5.77 min., 50.20-50.23 ^{o}C at 45% hydration level for macaroni noodles made from flour blends containing 0 to 100% cassava starch (Table 4.8). The RVA curves obtained for macaroni noodles made with 30 and 100% cassava incorporation at 50% hydration levels are shown as representative of those obtained in this study (Fig. 4.5). The viscosities of the macaroni noodles (Table 4.8) were lower than those obtained for the raw flour blends (Table 4.5) and this decrease extends to the holding period (at 95 ^{o}C) for all the samples. A possible explanation for

Table 4.8 Effect of substituting durum wheat semolina with cassava starch on rapid visco-analysis of cassava-semolina macaroni noodles made at three hydration levels

Level of cassava starch incorporation	Hydration Level (%)	Peak Viscosity (RVU)	Holding Strength (RVU)	Break Down (RVU)	Final Viscosity (RVU)	Setback (RVU)	Peak Time (mins.)	Pasting Temp (^{o}C)
100%Durum wheat semolina	45%	27.55^{k}	22.843^{l}	4.71^{j}	52.88^{i}	30.04^{i}	5.77^{a}	50.20^{abcd}
	50%	25.04^{k}	20.38^{l}	4.67^{j}	49.42^{i}	29.05^{i}	5.72^{ab}	50.15^{abcd}
	55%	25.54^{k}	20.46^{l}	5.09^{j}	49.00^{i}	28.54^{i}	5.77^{a}	50.28^{ab}
20%Cassava starch	45%	45.71^{hi}	38.55^{j}	7.17^{i}	77.84^{h}	39.29^{h}	5.59^{bcd}	50.23^{abcd}
	50%	40.59^{j}	33.71^{k}	6.88^{i}	72.92^{h}	39.21^{h}	5.71^{ab}	50.10^{cd}
	55%	43.50^{ij}	35.21^{jk}	8.29^{hi}	74.21^{h}	39.00^{h}	5.69^{ab}	50.25^{abc}
30%Cassava starch	45%	55.09^{g}	45.63^{i}	9.46^{gh}	92.05^{g}	46.42^{g}	5.66^{abc}	50.18^{abcd}
	50%	44.13^{ij}	36.17^{jk}	7.96^{i}	74.21^{h}	38.05^{h}	5.62^{abcd}	50.30^{a}
	55%	48.96^{h}	38.13^{j}	10.83^{g}	78.00^{h}	39.88^{h}	5.51^{cde}	50.13^{bcd}
50%Cassava starch	45%	70.13^{f}	57.13^{h}	13.00^{f}	104.08^{fg}	46.96^{fg}	5.46^{de}	50.20^{abcd}
	50%	79.17^{e}	63.84^{g}	15.34^{e}	116.04^{de}	52.21^{de}	5.40^{e}	50.23^{abcd}
	55%	71.63^{f}	57.79^{h}	13.84^{f}	104.05^{g}	46.25^{g}	5.48^{de}	50.23^{abcd}
70%Cassava starch	45%	104.75^{c}	72.96^{cd}	31.80^{c}	122.54^{ef}	49.59^{ef}	4.92^{f}	50.23^{abcd}
	50%	101.34^{dc}	74.71^{c}	26.63^{d}	127.42^{d}	52.71^{d}	4.99^{f}	50.20^{abcd}
	55%	99.59^{d}	68.58^{ef}	31.00^{c}	117.21^{fg}	48.63^{fg}	4.86^{f}	50.25^{abc}
100%Cassava starch	45%	145.08^{b}	100.13^{b}	44.96^{b}	169.29^{b}	69.17^{b}	4.01^{h}	50.23^{abcd}
	50%	154.96^{a}	103.83^{a}	51.13^{a}	174.46^{ab}	70.63^{ab}	3.98^{h}	50.08^{d}
	55%	98.42^{d}	70.54^{de}	27.88^{d}	128.38^{c}	57.84^{c}	4.46^{g}	50.13^{bcd}
Commercial Macaroni		79.59^{e}	66.54^{fg}	13.05^{f}	140.25^{a}	73.71^{a}	5.63^{abcd}	50.20^{abcd}

RVU=Rapid Viscosity Unit; Values are means of two replicates. Values with same superscripts along the column are not significantly different at P>0.05

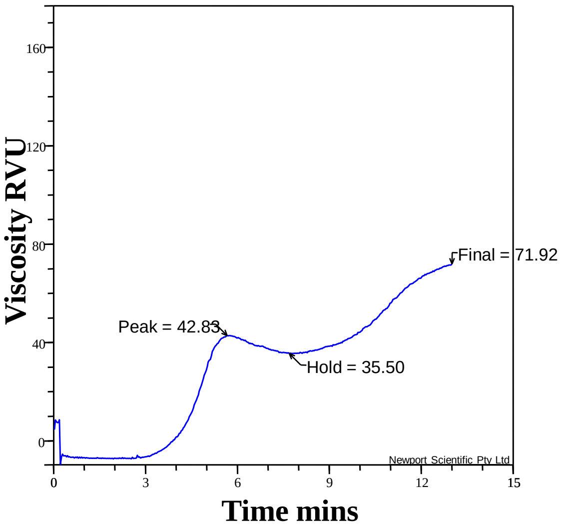


Figure a

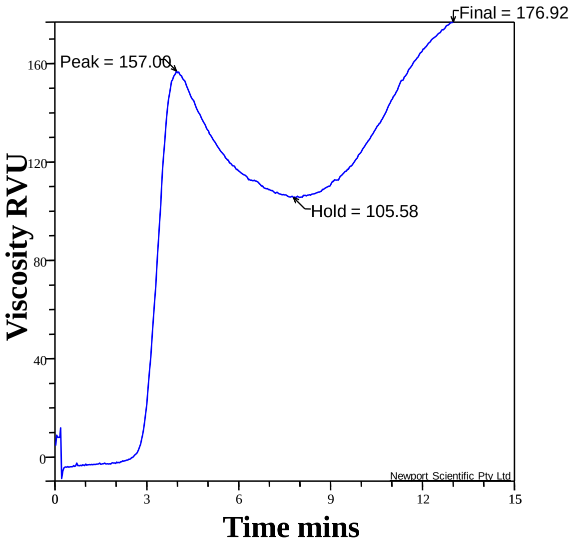


Figure b:

Fig. 4.5 Representative curves of RVA
a= 30% Cassava starch, 50% Hydration; b=100% Cassava starch, 50% Hydration

this phenomenon has been associated with granule disintegration and hydrolysis of amylose chains by hydrogen ions (Hoover and Susulski, 1985). Similar trend was reported by Kim *et al* (1996) for potato starch noodles.

Lee *et al* (1995) believed that amylose content have a marked influence on the breakdown viscosity, which is a measure of susceptibility of cooked starch granules to disintegration. In this study, amylose content of the macaroni samples increased from 17.4% to 18% with 20% cassava starch inclusion, and up to 21.73% at 70% cassava inclusion (when averaged over the three hydration levels), thus accounting for the increasing breakdown viscosity (Table 4.8) and the subsequent cooking losses (Table 4.11) observed.

There was little or no variation with peak time, varying between 5-6 min except for 100% cassava starch macaroni, which had lower peak time of about 4min. As shown in Table 4.9, variation in pasting temperature was minimal; values were 50.06 ^{o}C for 100% cassava macaroni at 50% hydration and 50.3^{o}C for 30% cassava incorporation at 50% hydration. Similar observation was made for the raw flour blends (Table 4.5), and this is probably connected with the similarity between the granular size of cassava (3-28 µm) and durum wheat (3-34 µm) (Table 2.9) and a possible indication of similar degree of crosslinking within the amylopectin polymer (Anonymous, 2012).

Correlations among the pasting characteristics and the physicochemical properties of wheat semolina macaroni noodles are shown in Appendix 9. Except for pasting temperature, most of the pasting parameters correlated very highly with one another. Peak viscosity correlated positively at 0.1% level of probability with holding strength (r = 0.99), breakdown (r = 0.97), final viscosity (r = 0.97), setback (r = 0.87), but negatively with peak time (r = -0.94). A weak but positive correlation existed between peak viscosity and soluble loss (r = 0.69) at same level of significance. Swelling volume was significantly correlated with water absorption index (r = 0.95). Similar correlations were reported by Bhattacharya *et al*, (1999) among physicochemical properties of rice noodles. Also, studies on wheat noodle quality have also shown similar significant correlation between swelling power, swelling volume, peak viscosity, and wheat noodle texture, and Toyokawa *et al* (1989) and Crosbie (1991) have established these parameters as rapid, alternative measurements for predicting wheat noodle quality.

4.3.5 Microbiological analysis of dried macaroni noodles

The microbial quality of cassava-semolina macaroni noodles is shown in Table 4.9. There was no detectable colony forming unit (cfu) observed in all the samples up to 30% substitution levels. Mold and yeast count were 33 and 100 cfu/g at 70 and 100% substitution of wheat semolina with cassava starch respectively. Also, microbial growth observed at 50%, 70% and 100% cassava inclusions were 6,830, 33,300 and 83, 300 cfu/g aerobic plate count (APC), due presumably to some microbial contamination during the preparation of cassava starch. Nonetheless, according to the "Code of Good Manufacturing Practices" of the Codex Alimentarius and to the relevant laws of Indonesia (SNI 01-2974 -1996); dried noodle products are considered safe and suitable for human consumption, when APC is <100,000 cfu/g and yeast and mould count <1,000 cfu/g. Similar guideline was arrived at by a working group of the Public Health advisory committee for food and dairy products (Gilbert *et al*., 2000). Same safe limit was specified by Nigerian industrial standard for macaroni, spaghetti, noodles and allied products (SON, 2001) and likewise stipulated by Hayma (2003). Neither coliforms nor any organism of public health significance was detected in the samples produced in this study.

4.3.6 Mineral content of dried macaroni noodles

The mineral content of macaroni noodles is shown in Table 4.10. Values obtained compares favourably well with those obtained from the USDA computerized Nutrient Data Bank as reported by Doughlass and Matthews (1982). As cassava incorporation increased from 20 to 70%; iron and calcium contents increased from 28.9 to 72.0 and 627.5 to 819.1 mg/kg, respectively. These values were higher than that obtained for commercial macaroni (20.97-92.37 mg/kg). The reverse is however the case with respect to zinc, potassium, sodium, magnesium and phosphorus; whose values decreased with increasing cassava incorporation. Commercial macaroni had higher potassium (2457.53 mg/kg) but lower sodium (8.97 mg/kg) contents compared to the developed macaroni. The latter could be attributed to the added salts- (table salt, Na and K carbonates) during macaroni production. Nevertheless, Doughlass and Matthews (1982) reported much

Table 4.9 Microbial count[a] of cassava-semolina macaroni noodles*

Macaroni Noodles made from	Mould & Yeast Count (cfu/g)	Aerobic Plate Count (cfu/g)
100%Durum wheat semolina	Not detected in 25g	Not detected in 25g
20% Cassava starch	Not detected in 25g	Not detected in 25g
30% Cassava starch	Not detected in 25g	Not detected in 25g
50% Cassava starch	Not detected in 25g	6.83×10^3
70% Cassava starch	0.33×10^2	3.33×10^4
100% Cassava starch	1.00×10^2	8.33×10^4
Commercial Macaroni	Not detected in 25g	Not detected in 25g

a=Microbial count was carried out 6 weeks after production

*****No coliforms were detected in all the samples

Table 4.10 Effect of substituting Durum wheat semolina with Cassava starch on Mineral composition of cassava-semolina macaroni noodles made at three hydration levels

Level of cassava starch incorporation	Hydration Level (%)	Iron	Zinc	Calcium	Potassium	Magnesium	Sodium	Phosphorus
100% Durum wheat semolina	45%	25.38^{k}	21.54^{b}	461.40^{i}	1989.67^{b}	590.62^{a}	5491.98^{a}	9514.09^{a}
	50%	23.18^{l}	17.74^{d}	517.05^{h}	1913.64^{b}	587.50^{a}	4920.45^{d}	9443.18^{a}
	55%	22.27^{lm}	21.67^{b}	576.98^{f}	1876.54^{bc}	587.56^{a}	5221.37^{bc}	9376.65^{a}
20% Cassava starch	45%	28.05^{j}	15.24^{e}	787.29^{cd}	1762.58^{cd}	527.53^{b}	4940.19^{d}	8204.69^{c}
	50%	26.35^{jk}	15.21^{e}	559.34^{fg}	1961.02^{b}	530.79^{b}	5100.28^{c}	8422.61^{b}
	55%	32.43^{i}	15.02^{e}	535.77^{gh}	1963.30^{b}	524.28^{b}	5280.10^{b}	8274.23^{bc}
30% Cassava starch	45%	39.09^{gh}	13.02^{g}	804.85^{c}	1636.17^{e}	460.07^{d}	4194.45^{hi}	6610.10^{d}
	50%	38.20^{h}	45.89^{a}	557.42^{fg}	1672.67^{de}	435.95^{e}	4197.55^{hi}	6357.06^{e}
	55%	39.19^{gh}	13.91^{f}	974.41^{a}	1760.73^{cd}	473.77^{c}	4284.08^{gh}	6690.72^{d}
50% Cassava starch	45%	40.90^{g}	11.03^{hi}	877.95^{b}	1448.70^{fg}	424.92^{f}	3744.57^{j}	5324.72^{f}
	50%	44.69^{f}	11.22^{h}	535.36^{gh}	1488.42^{f}	379.96^{g}	4430.80^{f}	5200.83^{f}
	55%	48.04^{e}	9.28^{j}	529.87^{gh}	1340.99^{gh}	341.51^{h}	3692.91^{j}	4688.49^{g}
70% Cassava starch	45%	74.56^{b}	7.95^{l}	915.60^{b}	1217.73^{i}	294.31^{i}	4365.66^{fg}	4390.19^{h}
	50%	62.44^{d}	8.70^{k}	762.66^{d}	1292.36^{hi}	290.38^{i}	4717.24^{e}	3959.72^{i}
	55%	79.00^{a}	0.61^{i}	778.91^{cd}	1366.04^{gh}	289.33^{i}	4586.42^{e}	4067.21^{i}
100% Cassava starch	45%	78.37^{a}	5.06^{n}	684.58^{e}	946.03^{j}	189.98^{j}	4060.20^{i}	2507.42^{j}
	50%	67.81^{c}	6.39^{m}	807.01^{c}	865.73^{j}	190.54^{j}	4232.51^{gh}	2342.57^{j}
	55%	78.07^{a}	4.06^{o}	895.36^{b}	658.61^{k}	144.22^{k}	2529.94^{k}	1889.96^{k}
Commercial macaroni		20.97^{m}	18.60^{c}	92.37^{j}	2457.53^{a}	530.914^{b}	8.97^{l}	8277.69^{bc}

Values are means of two replicates. Values with same superscripts along the column are not significantly different at P>0.05

4.3.7 Cooking characteristics

Cooking characteristics shown in Tables 4.11a, b and c are for cassava-wheat semolina macaroni noodles made at 45, 50 and 55% levels of hydration (in respective order) for 0 to 100% substitution of durum wheat semolina with cassava starch. Optimum cooking time ranged between 4.5 to 9 min at 45% hydration level and between 5 to 9 min at both 50 and 55% hydration levels. At all hydration levels considered, the least optimum cooking time was obtained for 100% cassava starch macaroni while the highest was for macaroni containing 20% cassava starch inclusion. As shown in Table 4.11, with 20% cassava starch inclusion, optimum cooking time increased from 6 to 9 min (at 45% hydration), from 6.5 to 9 min (at 50% hydration) and from 7 to 9 min (at 55% hydration). The initial increase in optimum cook time at 20% cassava inclusion is not unassociated with the presence of nontraditional ingredient (cassava starch) which affects hydration characteristics. Cassava reportedly has high level of crystallinity, which imparts higher structural stability so that the water molecules need longer time to penetrate the crystalline areas (Barichello *et al.*, 1990). Probably, as observed in rice, amylose crystallites in the mixed starches could create a three-dimensional network by strongly linking short starch chains at junction zones causing it to take a longer time for water to penetrate beneath the surface of pasta (compact structure formed by the hydrophobic protein) during cooking so as to effect starch swelling, gelatinization and cooking (Yoenggudahal and Noomhorn 2002). Thereafter further increase in cassava starch inclusion, from 20 to 100% caused reduction in optimum cooking time, probably because as cassava starch concentration increased, gluten content in blend reduced and the rigidity of the polymerized gluten network declines, easing water penetration and the subsequent quick cooking. When noodles are cooked in boiling water, cooking starts at the surface as the starch granules near the surface gain water, swell and proceeds towards the center.

However, the optimum cooking time obtained for laboratory prepared 100% durum wheat semolina at all levels of hydration (6 min) was much lower than that of its counterpart (11 min) sold commercially. Difference observed could be attributed not only to the laboratory processing conditions, but also the ingredient make-up (Manthey *et al.*,

Table 4.11 Effect of substituting Durum wheat semolina with Cassava starch on cooking characteristics of cassava-semolina macaroni noodles made at three hydration levels

a. 45% Hydration

Level of Cassava starch incorporation	Optimum Cooking Time(min.)	Water Absorption Index (g/g)	Swelling Volume (%)	Solid Loss (%)	Soluble Loss (%)	Total Cooking Loss (%)
100%Durum wheat semolina	6^{de}	109.62^{j}	96.27^{k}	16.88^{ed}	13.89^{def}	30.77^{g}
20%Cassava starch	8.75^{b}	130.88^{g}	130.00^{f}	18.71^{bcd}	13.33^{def}	32.04^{de}
30%Cassava starch	7.00^{c}	129.78^{g}	116.22^{h}	18.38^{cde}	13.37^{def}	31.74^{de}
50%Cassava starch	5.50^{ef}	162.50^{d}	165.10^{b}	9.57^{j}	$12.76e^{fg}$	22.34^{j}
70%Cassava starch	5.00^{fg}	194.60^{b}	187.56^{a}	6.84^{k}	8.73^{i}	15.57^{l}
100%Cassava starch	4.50^{g}	89.73^{l}	78.57^{n}	13.05^{ghi}	28.03^{b}	41.07^{b}

b. 50% Hydration

Level of Cassava starch incorporation	Optimum Cooking Time (mins.)	Water Absorption Index (g/g)	Swelling Volume (%)	Solid Loss (%)	Soluble Loss(%)	Total Cooking Loss(%)
100%Durum wheat semolina	6.50^{cd}	99.90^{k}	85.37^{m}	13.65^{g}	13.25^{def}	26.90^{e}
20%Cassava starch	9.00^{b}	74.82^{m}	79.21^{n}	13.00^{ghi}	13.89^{def}	26.89^{g}
30%Cassava starch	7.00^{c}	124.47^{h}	127.84^{g}	13.08^{gh}	11.34^{gh}	24.42^{i}
50%Cassava starch	6.00^{de}	149.26^{e}	135.29^{e}	16.23^{ef}	10.29^{hi}	26.52^{gh}
70%Cassava starch	6.00^{de}	150.91^{e}	149.50^{c}	11.08^{hij}	13.02^{def}	24.11^{i}
100%Cassava starch	5.00^{fg}	88.64^{l}	78.66^{n}	$10.92h^{ij}$	33.75^{a}	44.66^{a}

c. 55% Hydration

Level of Cassava starch incorporation	Optimum Cooking Time (mins.)	Water Absorption Index (g/g)	Swelling Volume (%)	Solid Loss (%)	Soluble Loss (%)	Total Cooking Loss (%)
100%Durum wheat semolina	7.00^{c}	90.51^{l}	86.92^{l}	20.66^{ab}	12.54^{fg}	33.20^{d}
20%Cassava starch	9.00^{b}	117.83^{i}	107.29^{i}	21.93^{a}	5.12^{j}	27.05^{g}
30%Cassava starch	7.00^{c}	100.90^{k}	98.29^{j}	13.03^{ghi}	14.22^{de}	27.25^{g}
50%Cassava starch	6.65^{cd}	121.44^{h}	126.71^{g}	14.49^{fg}	14.59^{d}	29.08^{f}
70%Cassava starch	6.00^{de}	175.77^{c}	137.39^{d}	10.83^{ij}	14.29^{de}	25.12^{hi}
100%Cassava starch	5.00^{fg}	214.21^{a}	187.13^{a}	$20.00a^{bc}$	19.31^{c}	39.31^{c}
Commercial Macaroni	11.00^{a}	137.25^{f}	105.88^{i}	6.18^{k}	13.28^{def}	19.46^{k}

Values are means of two replicates. Values with same superscripts along the column are not significantly different at P>0.05

2004) which include emulsifiers (soy-flour and soy-oil), binders (gum Arabic) and stabilizers (gelatin).

With 20% substitution of durum wheat semolina with cassava starch, water absorption index (WAI) increased from 109.62 to 130.88 g/g and from 90.51 to 117.83 g/g at 45 and 55% levels of hydration respectively. A decline in WAI was observed (from 99.9 to 74.82 g/g) at 50% hydration level. It was generally observed that from 30 to 70% cassava starch inclusion, WAI consistently increased from 129.78 to 194.6 g/g, 124.47 to 150.91 g/g, and 100.9 to 175.77 g/g respectively for the three hydration levels. A similar trend was observed for swelling volume at these hydration levels, and could be explained with the strong intermolecular bonds and high amylose content of wheat starch which reduces swelling at initial stage (Brandam *et al*., 2003) , but thereafter the relative fragility of cassava starch granules allows increased swelling. This is in agreement with Moorthy and Ramanujam (1982) who suggested that the associative forces in cassava starch are decisive in determining its swelling property.

At 45% hydration level (Table 4.11a), the maximum cooking loss observed was 28% (soluble loss) for 100% cassava macaroni, while the least was 6.84% (solid loss) for 70% cassava starch concentration. At 50% hydration level (Table 4.11b), the maximum cooking loss observed was 33.75% (soluble loss) for 100% cassava macaroni, while the least was 10.29% (soluble loss) for 50% cassava starch concentration. Also, at 55% hydration level (Table 4.11c), the maximum cooking loss observed was 21.93% (solid loss) for 20% cassava starch concentration in macaroni, while the least was 5.12% (solid loss) for 20% cassava starch concentration. These losses are associated with leaching of soluble amylose and subsequent surface disintegration of starch granules into the cooking water as cooking continues from macaroni surface to the inner portion. However in comparison, these cooking losses are higher than those obtained for commercial macaroni, solid loss of 6.18% and a soluble loss of 13.28%, due presumably to its strong gluten which polymerizes and protects the swollen and gelatinized starch.

Total cooking losses obtained ranged from 15.6% for macaroni made from 70% wheat substitution with cassava starch at 45% hydration level to 44.7% for macaroni made from 100% cassava starch at 50% hydration. High cooking loss observed for 100% cassava starch macaroni could be attributed to its high level of damaged starch (7.17%,

Table 4.1) and low falling number value (260 sec, Table 4.3). Chiang *et al*. (1973) associated high levels of damaged starch to increased baking time, decreased water penetration inside the product, and a higher loss of product during cooking. Pasta manufacturers have opined that even moderate levels of sprout damage are detrimental to pasta cooking quality, making many, especially North American and Japanese manufacturers, to demand a durum wheat falling number in excess of 300 sec for the manufacture of premium pasta products (Dexter *et al*., 1990).

Starch granules at the surface of macaroni probably gained so much water as cooking proceeded towards the center, making them become paste-like and subsequently resulting into solid and soluble losses (Kim *et al*., 1996; Kim and Wiesenborn, 1996). Cooking losses observed in this study were much higher than those reported by earlier workers for starch noodles. A cooking loss ranging from 0.2% for mung bean starch noodles to 3.8% for noodles made from sweet potato starch was obtained by Kim and Wiesenborn, (1996); and Kim *et al*. (1996) likewise reported a range of 2.8-3.4% for potato starch noodles. It could be observed that both soluble and solid losses obtained in this study was not with the exemption of 100% wheat semolina noodles, it is thus an indication that processing procedures and extruder type used may be responsible for these seemingly cooking losses. A similar observation was made by Kratzer, (2007) on cooking losses from pasta made from a single screw pasta extruder, cylinder-plunger system and a twin-screw extruder. Cooking loss was lowest for single-screw extrusion; slightly higher for the spaghetti that was extruded in the cylinder-plunger system and highest for spaghetti extruded in the twin-screw extruder. In this study, a single screw extruder was used (De-Longhi Pasta Italia extruder, Plate 2.2).

Nonetheless, losses observed in this study were comparable to those reported by Abecassis *et al*., (1994) for spaghetti made from durum wheat (minimum 9.6% and maximum of 51.5%) which were attributed to the extrusion conditions. Several research reports have been published concerning the quality of pasta made with nontraditional ingredients (Marconi and Carcea 2001; Lee *et al* 2002). These reports indicate that such pastas often had poorer cooking quality than those made from 100% semolina. But, it has also been reported that drying at high or ultrahigh temperatures improved cooking quality (Hou and Kruk 1998 Marconi and Carcea 2001; Manthey and Schorno 2002). In this current study, a possible explanation for the moderate cooking losses (compared to the maximum loss of 51.5%) observed, could be the high temperature used in drying cassava-wheat semolina macaroni noodles (70 ± 5 ^{o}C), after low temperature drying (at 38 ± 2 ^{o}C) (Zweifel *et al*. 2003). On the other hand, much lower losses were reported by Kim et al., (1996) for starch noodles from potato starch (2.8-3.4%) and edible bean starch (0.9-1.9%); and by Kim and Wiesenborn, (1996) for blends of mung bean and potato starches (0.2-3.8%).

Analysis of variance revealed that both cassava starch incorporation and hydration level interaction and their main effects were significant for weight of cooked macaroni, water absorption index, swelling volume, solid and soluble losses, and total cooking loss ($P<0.05$), but not for optimum cooking time (Appendix 4.6). However, Sinha and Manthey (2008) reported that neither the hydration level and flaxseed flour (oil-rich) concentration nor their main effects were significant for water absorption during cooking or cooking loss. The reduced cooking loss was attributed to the high water-binding capacity of the flaxseed gums (Sinha and Manthey, 2008) which differ from cassava starch properties. The latter's high water-binding capacity (147.5%) was probably associated with its starch component (Table 4.5). However, hydration level when considered as a main effect had no significance on the weight of uncooked macaroni used since optimum hydration had been attained

There was significant correlation between soluble loss and peak viscosity ($r = 0.69$), holding strength ($r = 0.65$) and final viscosity ($r = 0.64$),); while total cooking loss was negatively correlated to peak time ($r = -0.54$) at $P<0.05$. Thus soluble loss increased with increasing peak viscosity, holding strength, final viscosity. Increased peak time and reduced solid loss will result in reduced total cooking loss.

Colour of cooked cassava- wheat semolina macaroni noodles was observed over a period of 24 hours (Fig.4.6). Brightness (L*) of colour compared to the control (commercial, market sample) was maintained during hours of study. On the other hand, all the samples had higher redness (a*) in comparison to the control except for macaroni samples containing 70 and 100% samples. The wide variation in a* values was however maintained during the 24 hours of observation. Yellowness (b*) of cooked macaroni

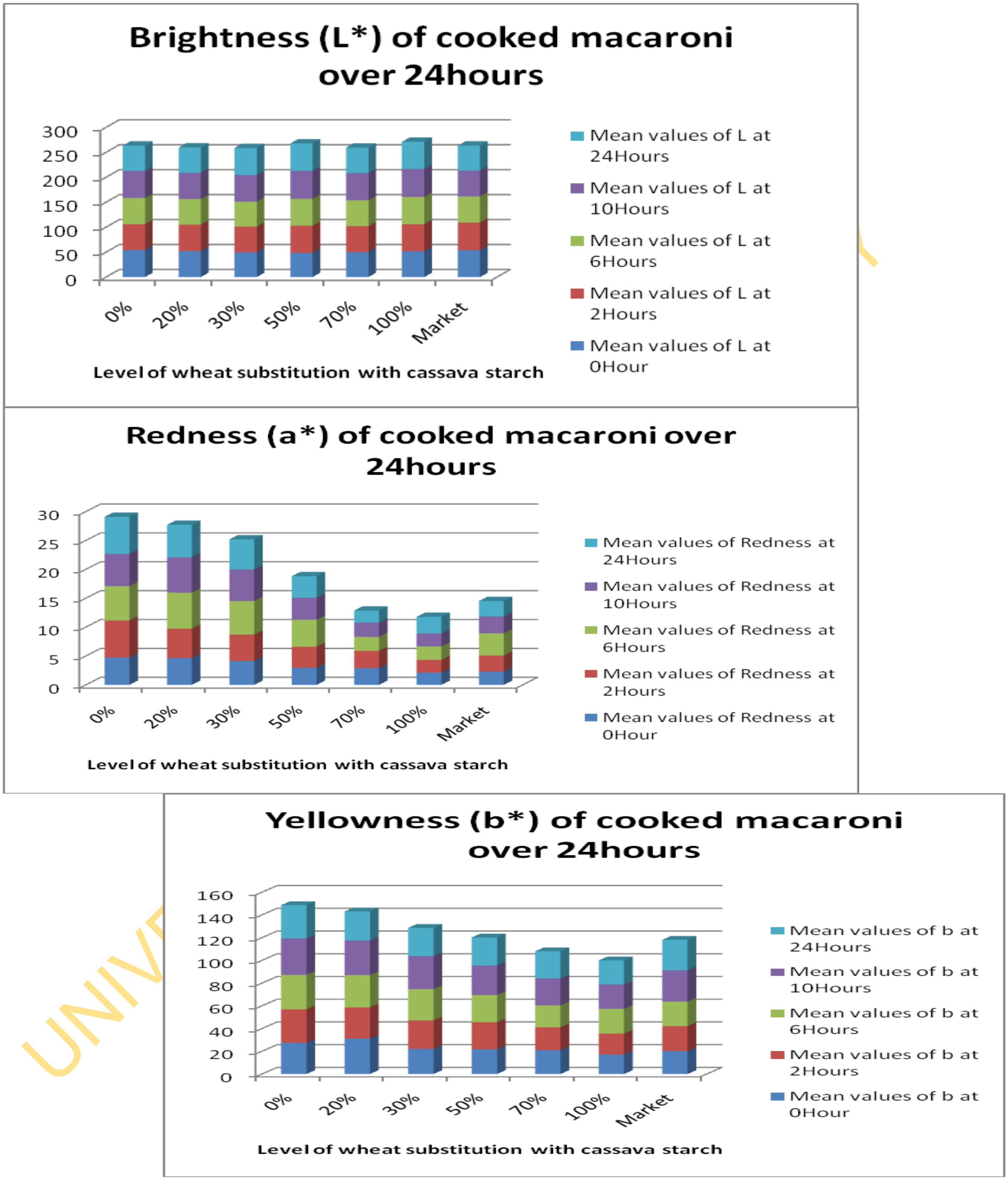


Figure 4.6 Colour of cooked macaroni at 0,2,6,10,&24 hours

increased with time but declined slightly with cassava incorporation, an indication that consumer appeal will not be adversely affected within 24-hours of cooking.

4.3.8 Sensory Properties

Sensory properties of macaroni noodles made at 45, 50 and 55% levels of hydration for 0 to 100% substitution of durum wheat semolina with cassava starch are shown in Tables 4.12. Noodles made were evaluated for colour, appearance, firmness, stickiness, chewiness, elasticity, taste and overall acceptability by trained sensory panelists. Macaroni made with 100% wheat semolina was assigned the highest scores for colour (8.00), appearance (7.93), firmness (7.53), stickiness (7.47), chewiness (7.53), elasticity (7.33), taste (7.60) and overall acceptability (7.67) at 45% hydration level. With 20% substitution of durum wheat semolina with cassava starch, panelists maintained the choice of macaroni made at 45% hydration, probably due its firm texture and cohesiveness. Similar preference was made for fresh pastas made from semolina and extruded at low hydration (29%) in comparison with those made at higher hydration level (31%) (Sinha and Manthey, 2008). A deviation from this trend was observed with 30% cassava starch inclusion, in that panelists scores were higher for macaroni made at 50% hydration for colour (7.67), firmness (7.27), stickiness (7.00), chewiness (7.47), elasticity (7.07) and overall acceptability (7.40). A possible reason could be that the increased concentration of cassava starch necessitated additional water for cohesive dough development, due probably to the water binding properties of cassava starch (Manthey *et al.*, 2004). Beyond 50% cassava inclusion, low sensory scores (ranging from 1.47 to 3.93) were obtained for all parameters except for noodle colour. The highest sensory scores obtained for taste (7.67) and firmness (7.27) were for macaroni made from 30% wheat substitution at 45 and 50% hydration levels respectively. A similar observation made by Charles *et al*. (2006) indicated improved cooking and textural properties for wheat noodles containing 30% cassava starch.

Results obtained from the difference test (multiple comparison test), in comparison with the commercial durum wheat-based macaroni noodles, are shown in Table 4.13. From a scale of 5 in which 3 was equated in quality with the control (commercial macaroni, 100% wheat semolina), highest score of 2 for noodle firmness

Table 4.12 Sensory evaluation (preference test) of cassava-semolina macaroni noodles made with different levels of cassava starch and at three hydration levels

Level of Cassava starch incorporation	Hydration Level (%)	Colour	Appearance	Firmness	Stickiness	Chewiness	Elasticity	Taste	Overall Accept-ability
100%Durum wheat semolina	45%	8.00^{ab}	7.93^{a}	7.53^{a}	7.47^{a}	7.53^{a}	7.33^{ab}	7.60^{a}	7.67^{a}
	50%	7.33^{bcde}	7.53^{abc}	7.20^{ab}	7.20^{a}	7.27^{abc}	7.33^{ab}	7.33^{ab}	7.47^{ab}
	55%	7.40^{abcde}	7.13^{bcd}	7.07^{abc}	6.73^{abc}	6.67^{bcd}	6.53^{cd}	6.67^{b}	6.47^{de}
20%Cassava starch	45%	8.07^{a}	7.73^{ab}	7.07^{abc}	7.47^{a}	7.60^{a}	7.73^{a}	7.60^{a}	7.60^{ab}
	50%	7.07^{defg}	7.00^{cde}	6.60^{bcd}	6.87^{abc}	7.13^{abc}	6.67^{bcd}	7.13^{ab}	6.67^{cde}
	55%	6.60^{fgh}	6.60^{def}	6.40^{cd}	6.73^{abc}	7.00^{abcd}	7.07^{abc}	7.13^{ab}	6.87^{bcde}
30%Cassava starch	45%	7.33^{bcde}	7.33^{abc}	7.20^{ab}	6.73^{abc}	7.33^{abc}	6.93^{bc}	7.67^{a}	7.07^{abcd}
	50%	7.67^{abcd}	7.13^{bcd}	7.27^{ab}	7.00^{ab}	7.47^{ab}	7.07^{abc}	7.53^{a}	7.40^{abc}
	55%	6.80^{efgh}	6.33^{ef}	7.13^{ab}	6.33^{bc}	7.20^{abc}	7.00^{abc}	7.20^{ab}	7.40^{abc}
50%Cassava starch	45%	7.80^{abc}	7.33^{abc}	6.73^{bcd}	7.13^{ab}	7.20^{abc}	6.73^{bc}	7.53^{a}	7.33^{abc}
	50%	6.73^{efgh}	5.93^{f}	6.07^{d}	6.07^{c}	6.27^{d}	5.93^{d}	7.00^{ab}	6.20^{e}
	55%	7.33b^{cde}	7.47^{abc}	6.80^{bc}	6.80^{abc}	6.60^{cd}	7.00^{abc}	7.13^{ab}	7.33^{abc}
70%Cassava starch	45%	6.80^{efgh}	4.73^{g}	5.20^{e}	4.73^{d}	5.00^{e}	4.73^{e}	5.53c	5.20^{f}
	50%	7.20^{cdef}	4.73^{g}	4.87^{ef}	4.20^{ed}	4.53^{ef}	4.07^{ef}	5.13^{cd}	4.47^{fg}
	55%	7.13^{cdefg}	4.27^{g}	4.40^{f}	3.80^{e}	3.73^{fg}	3.60^{fg}	4.60^{de}	4.00^{g}
100%Cassava starch	45%	6.53^{fgh}	2.93^{h}	2.60^{g}	2.47^{f}	3.07^{gh}	3.00^{gh}	3.93^{ef}	2.93^{h}
	50%	6.13^{h}	2.47^{h}	2.20^{gh}	2.27f^{g}	2.53^{h}	2.93^{gh}	3.67^{f}	2.40^{hi}
	55%	6.47^{gh}	2.40^{h}	1.80^{h}	1.47^{g}	1.67^{i}	2.53^{h}	3.40^{f}	1.87^{i}
LSD		0.71	0.7	0.73	0.82	0.86	0.74	0.73	0.78

Values are mean scores of fifteen panelists. Same superscripts within the column indicate no significant difference at $P > 0.05$

Table 4.13 Sensory evaluation (difference test) of cassava-semolina macaroni noodles made with different levels of cassava starch

Preferred macaroni made from	Colour	Appearance	Firmness	Stickiness	Chewiness	Elasticity	Taste	Overall Accept-ability.
100%durum wheat semolina	1.33^{cd}	1.60^{b}	2.00^{a}	1.93^{a}	1.93^{a}	1.73^{a}	1.67^{a}	1.73^{b}
20%cassava starch	1.13^{d}	1.40^{b}	1.67^{ab}	1.40^{bc}	1.60^{abc}	1.27^{a}	1.73^{a}	1.27^{c}
30%cassava starch	1.87^{ab}	1.73^{ab}	1.73^{ab}	1.47^{bc}	1.80^{ab}	1.67^{a}	1.93^{a}	1.80^{ab}
50%cassava starch	2.2^{a}	2.13^{a}	1.87^{a}	1.80^{ab}	1.93^{a}	1.73^{a}	1.93^{a}	2.20^{a}
70%cassava starch	1.4^{cd}	1.40^{b}	1.33^{b}	1.47^{bc}	1.47^{bc}	1.33^{a}	1.40^{a}	1.53^{bc}
100%cassava starch	1.73^{bc}	1.40^{b}	1.33^{b}	1.13^{c}	1.20^{c}	1.40^{a}	1.73^{a}	1.13^{c}
LSD	0.45	0.43	0.42	0.43	0.45	0.47	0.54	0.42

Values are averages of two replicates from fifteen panelists. Same superscripts indicate no significant difference at $P > 0.05$

was obtained for macaroni made from 100% durum wheat semolina. Sensory evaluation scores obtained for 20-100% wheat substitution with cassava starch ranged from 1.13 to 2.2 for colour, 1.4 to 2.13 for appearance, 1.33 to 1.87 for firmness, 1.13 to 1.80 for stickiness, 1.20 to 1.93 for chewiness, 1.27 to 1.73 for elasticity, 1.40 to 1.93 for taste and 1.13 to 2.20 for overall acceptability. For all the sensory parameters considered, panelists judged macaroni noodles made from 50% cassava inclusion as being acceptable.

In terms of taste, macaroni noodles made from 30 and 50% wheat substitution with cassava starch were assessed to be closest to commercial, market macaroni 'R', indicating the limit to which durum wheat could be substituted with cassava starch, without imparting negatively on taste. However, with reference to colour, appearance, elasticity and overall acceptability, macaroni made from 50% wheat substitution with cassava starch was assessed to be closest to 'R'. Ranking results further indicated that it was the most acceptable of the developed starch noodles. This is an indication that cassava starch and durum wheat semolina, were complimentary with respect to their functional characteristics on the developed macaroni noodles. There was no significant difference between macaroni made from 100% wheat semolina and those made from 50% cassava starch inclusion in terms of firmness, chewiness, elasticity, and taste at $P > 0.05$ (Table 4.13). A similar conclusion of 50: 50 blending ratio was reached by Singh *et al*., 2010 after studying the suitability of rice and potato starches in making noodles, with respect to their reduced cooking time, higher cooked weight, transparency and slipperiness.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Cassava-wheat semolina macaroni noodles, with acceptable nutritional, microbiological and sensory qualities were developed from flour blends of high quality cassava starch mixed with durum wheat semolina. Calcium, iron and energy contents of macaroni were improved and optimum cooking time was reduced from 11 to 7 min.

Analysis of variance revealed that the interaction of the two factors of this research study (i.e. cassava starch inclusion and hydration level variation) had significant effect on protein and ash contents at 0.1% level, while hydration level and their interaction had no significant effect at 5% probability level. Pasting temperature was not affected by either of the two factors nor their interaction at 5% probability level. Both factors had significant effect on the breaking force of dried uncooked macaroni noodles, brightness and yellowness of colour, amylose, sugar and starch contents with the exception of bulk density and redness of colour at 5% probability level of significance.

Moderate soluble (5.12-14.59%) and solid losses (6.84-21.93%) were obtained on cooking, for cassava-wheat semolina macaroni noodles made from flour blends containing 20-70% cassava starch.

From sensory evaluation, inclusion of cassava starch improved sensory judgment for colour and appearance and there was no significant difference between macaroni made from 100% wheat semolina and those made from 50% substitution with cassava starch in terms of firmness, chewiness, elasticity, and taste at 5% level of probability. Thus indicating that cassava starch had complimentary functional characteristics when blended with durum wheat semolina at 50: 50 (w/w) mixing ratio. Macaroni prepared at 45% level of hydration was the closest to the commercial market macaroni, having the highest sensory scores for colour, appearance, firmness, stickiness, elasticity and overall acceptability.

5.2 Recommendations and further work

This procedure developed for cassava-wheat semolina macaroni noodles needs to be industrially tested, as it would ease its adoption for commercialization on small, medium and large scale production levels. It would thus increase food production, generate more revenue for cassava farmers, reduce dependence on durum wheat importation, add variety to foods available and contribute to household food security for both rural and urban population in Nigeria. The procedure will be useful for developing a processing protocol for other pasta products using non-traditional ingredients that lack gluten.

Research results of this study will contribute to realizing the industrial potential of cassava in Nigeria and the production of cassava based noodle/pasta products would lead to increased investment opportunities for cassava processors, entrepreneurs and investors, leading to industrial growth as well as employment generation in both rural and urban areas of Nigeria. This research is in line with Federal Government's Policy on import substitution, export promotion, economic diversification from crude oil and should be added to the cassava – initiatives initiated by the Federal Government of Nigeria.

It would eventually pave way for the export of cassava noodle products into other West African countries that are already accustomed to cassava consumption. Other similar products that would meet local tastes and food customs would subsequently be developed in cassava growing areas of Africa. The production of cassava flour and starch, on commercial scale would also be accelerated and these products would be available for small and medium scale investors to further process into various consumable food products, thus contributing significantly to the nation's economy and societal wellbeing.

Further characterization of native cassava starch, investigation into the suitability of using modified cassava starch and subsequent fortification of macaroni (and other noodle/pasta products) with indigenous legumes should be carried out. A more critical examination of 30-50% wheat semolina substitution levels should be undertaken and the use of higher drying temperature investigated. Texture of dough, cooked and uncooked macaroni need to be determined instrumentally.

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APPENDICES

Appendix 3.1: Picture of cassava-semolina macaroni noodles

Appendix 3.2

Definition of key sensory attributes as it relates to starch macaroni noodles*

Sensory attribute	Explanation offered during training sessions
Stickiness	Degree to which surface of cooked macaroni adheres to each other or sticks to a hand feel
Firmness	Degree of resistance of the cooked macaroni when pressed between the fingers or chewed.
Elasticity	Degree to which starch macaroni noodle recover its original shape after deformation by the fingers/teeth.
Chewiness	Length of time required to masticate one macaroni strand at a constant rate of force application to reduce it to a consistency suitable for swallowing

*Selected panelists were trained in two successive sessions and sensory terms explicitly explained. Same individual was used each time and score sheets compiled accordingly.

Appendix 4.1

Analysis of variance of macaroni noodle doughs made with different levels of cassava starch and at three hydration levels

		F Values				
Sources of Variation	Degree of Freedom	Moisture	pH	Brightness (L)	Redness (a)	Yellowness (b)
Wheat substitution with Cassava starch	5	253.47***	44.00 ***	52.81***	13.35***	183.58***
Hydration level	2	671.36***	35.44***	45.20***	0.08	10.03***
Cassava starch X Hydration	10	43.45***	16.60***	1.51	4.05**	5.87***
Error	18					

* Significant at 5% level of probability.

** Significant at 1% level of probability.

*** Significant at 0.1%level of probability.

Appendix 4.2

Analysis of variance of proximate composition and energy of cassava-semolina macaroni noodles made with different levels of cassava starch and at three hydration levels

Sources of Variation	Degree of Freedom	F Values					
		Moisture	Protein	Fat	CHO	Ash	Energy
Wheat substitution with Cassava starch	5	632.46***	255.31***	370.87***	500.20***	170.74***	299.73***
Hydration level	2	20.75***	0.51	1021.39***	9.39**	2.01	619.67***
Cassava starch X Hydration	10	7.82***	1.38	5.36**	1.14	2.03	14.00***
Error	18						

* Significant at 5% level of probability.

** Significant at 1% level of probability.

*** Significant at 0.1%level of probability.

Appendix 4.3

Analysis of variance of physical and physicochemical properties of cassava-semolina macaroni noodles made with different levels of cassava starch and at three hydration levels

		F Values							
Sources of variation	Degree of Freedom	Bulk Density	Break Force	Brightness (L)	Redness (a)	Yellowness (b)	Amylose	Sugar	Starch
Wheat substitution with Cassava starch	5	4.24*	408.98***	83.47***	0.76	1031.94***	13.4***	4.23 (0.0102)	7.97 (0.0004)
Hydration level	2	0.4	186.68***	21.18***	2.3	19.16***	2.98	0 (0.9983)	1.69 (0.213)
Cassava starch X Hydration	10	2	28.58***	12.69***	0.83	9.34***	0.27***	2.91 (0.0233)	4.32 (0.0035)
Error	18								

* Significant at 5% level of probability.
** Significant at 1% level of probability.
*** Significant at 0.1%level of probability.

Appendix 4.4

Analysis of variance of rapid visco-analyses (RVA) of cassava-semolina macaroni noodles made with different levels of cassava starch and at three hydration levels

Sources of Variation	Degree of Freedom	F Values						
		Peak viscosity	Holding strength	Breakdown	Final viscosity	Setback	Peak time	Pasting temperature
Wheat substitution with Cassava starch	5	2254.82***	1433.90***	2558.67***	1310.97***	401.29***	334.56***	0.93 (0.4866)
Hydration level	2	90.98***	77.79***	50.23***	72.23***	22.40***	1.95	0.78 (0.4731)
Cassava starch X Hydration	10	73.51***	39.79***	116.51***	34.20***	10.16 ***	4.88**	1.61 (0.1808)
Error	18							

* Significant at 5% level of probability.

** Significant at 1% level of probability.

*** Significant at 0.1%level of probability.

Appendix 4.5

Analysis of variance of mineral profile of cassava-semolina macaroni noodles made with different levels of cassava starch and at three hydration levels

Sources of variation	Degree of Freedom	F-Values						
		Iron	Zinc	Calcium	Potassium	Magnesium	Sodium	Phosphorus
Wheat substitution with Cassava starch	5	2582.33 ***	5206.16 ***	219.42 ***	313.5 ***	8604.28 ***	531.81 ***	6155.3 ***
Hydration level	2	104.22 ***	1769.46 ***	142.95 ***	1.49	82.1 ***	74.17 ***	29.18 ***
Cassava starch X Hydration	10	28.82 ***	2039.66 ***	100.77 ***	6.11 **	52.68 ***	89.53 ***	12.1 ***
Error	18							

* Significant at 5% level of probability.
** Significant at 1% level of probability.
*** Significant at 0.1%level of probability.

Appendix 4.6

Analysis of variance of cooking properties of cassava-semolina macaroni noodles made with different levels of cassava starch and at three hydration levels

Sources of Variation	Degree of Freedom	F Values							
		Optimum cooking time	Weight of uncooked macaroni	Weight of cooked macaroni	Water absorption index	Swelling Volume	Solid Loss	Soluble Loss	Total Cooking Loss
Wheat substitution with Cassava starch	5	51.38***	3.41*	116.74***	1775.64***	7665.06***	43.22***	342.29***	403.95***
Hydration level	2	5.48*	1.87	41.83***	773.15***	2532.61***	39.84***	31.77***	9.23**
Cassava starch X Hydration	10	0.54	3.25*	59.62***	1033.87***	4289.83***	19.35***	51.07***	44.91***
Error	18								

***** Significant at 5% level of probability.

** Significant at 1% level of probability.

*** Significant at 0.1%level of probability.

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Appendix 4.7

Pearson’s correlation coefficients among physicochemical properties of cassava-semolina macaroni noodles

	Amyl	Break Force	PeakVisc	HS	BD Visc	Final Visc	SB Visc	Peak Time	PastT^{o}	Opt Ck T	WAI	SwVol	Solid Loss	Solu Loss
BrkF	-0.27													
PeakV	0.32	-0.54*												
HS	0.37	-0.51*	0.99***											
BDVisc	0.22	-0.59*	0.97***	0.93***										
FnlVisc	0.39	-0.4	0.97***	0.99***	0.89***									
SBVisc	0.39	-0.19	0.87***	0.91***	0.76***	0.96***								
PeakTm	-0.2	0.63***	-0.94***	-0.89***	-0.97***	-0.85***	-0.72***							
PastT^{o}	0.29	0.09	-0.21	-0.19	-0.23	-0.21	-0.24	0.27						
OptCkT	-0.15	0.73***	-0.52*	-0.46	-0.6*	-0.35	-0.13	0.64**	0.07					
WAI	0.56*	-0.36	0.27	0.3	0.21	0.28	0.23	-0.21	0.18	-0.28				
SwVol	0.47*	-0.42	0.2	0.23	0.13	0.2	0.12	-0.14	0.21	-0.31	0.95***			
SolidLos	-0.22	-0.14	-0.45	-0.47*	-0.39	-0.48*	-0.48*	0.25	0.15	0.07	-0.16	-0.14		
SoluLos	-0.17	-0.32	0.69***	0.65***	0.74***	0.64***	0.59*	-0.79***	-0.49*	-0.45	-0.27	-0.34	-0.16	
TotCkL	-0.28	-0.38	0.34	0.29	0.41	0.28	0.23	-0.54*	-0.35	-0.35	-0.34	-0.39	0.48*	0.79***

* Significant at 5% level of probability.

** Significant at 1% level of probability.

*** Significant at 0.1%level of probability.

Appendix 4.8

Pearson’s correlation coefficient between pasting properties of HQCS, DWS, and their blends versus cooking characteristics of developed macaroni

Para-meters	Peak Visc	Hold Str.	Break Down	Final Visc.	SetBack	Peak Time	Pastg. Temp.	Opt. Ck.Tm	Weight Unckd	Weight Cookd	WAI	SwVol	SolidLoss	SoluLoss
HoldStr	0.985***													
BreakD	0.997***	0.969**												
FnlVisc	0.911*	0.9496**	0.885*											
SetBack	-0.0667	0.0298	-0.109	0.338										
PeakTm	-0.749	-0.633	-0.794	-0.437	0.576									
PastgTmp	0.748	0.696	0.764	0.502	-0.533	-0.852*								
OptCkTm	-0.621	-0.588	-0.631	-0.538	0.142	0.65	-0.829*							
WtUnckd	-0.35	-0.501	-0.279	-0.611	-0.517	-0.282	-0.125	0.222						
WtCkd	0.137	0.113	0.146	-0.086	-0.636	-0.406	0.736	-0.581	-0.062					
WAI	0.154	0.139	0.16	-0.063	-0.626	-0.388	0.73	-0.538	-0.107	0.995***				
SwVol	0.035	-0.0013	0.0512	-0.24	-0.767	-0.385	0.654	-0.391	0.086	0.968**	0.972**			
SolidLoss	-0.0912	-0.09	-0.091	0.083	0.555	0.302	-0.685	0.603	0.162	-0.981**	-0.97**	-0.924*		
SoluLoss	0.966**	0.964**	0.957**	0.961**	0.14	-0.645	0.647	-0.667	-0.419	0.012	0.016	-0.136	-0.0011	
TotCkLoss	0.829*	0.828*	0.822	0.901*	0.368	-0.448	0.283	-0.337	-0.307	-0.417	-0.408	-0.525	0.436	0.9*

* Significant at 5% level of probability.

** Significant at 1% level of probability.

*** Significant at 0.1%level of probability.

Appendix 4.9

QUESTIONNAIRE ON THE SENSORY EVALUATION OF “MACARONI NOODLES” MADE FROM CASSAVA STARCH, DURUM WHEAT SEMOLINA AND THEIR BLENDS.

Dear Mr/Mrs/Miss----------------------------

This study is for research purpose only. Please evaluate each of these ***two sets*** of “**Macaroni Noodle**” samples, signifying your response for each organoleptic parameter on a nine-point hedonic scale. Kindly indicate your order of preference by ranking them 1st-2nd and 3rd in each set.

Name---------------- **Date--------------------------**

9- Like extremely
8- Like very much
7- Like moderately
6- Like slightly
5- Neither like nor dislike
4- Dislike slightly
3- Dislike moderately
2- Dislike very much
1- Dislike extremely

SENSORY ATTRIBUTES	SET ‘A’			SET ‘B’		
	101	122	133	154	175	166
Colour	☐	☐	☐	☐	☐	☐
Appearance	☐	☐	☐	☐	☐	☐
Firmness	☐	☐	☐	☐	☐	☐
Stickiness	☐	☐	☐	☐	☐	☐
Chewiness	☐	☐	☐	☐	☐	☐
Elasticity	☐	☐	☐	☐	☐	☐
Taste	☐	☐	☐	☐	☐	☐
Overall Acceptability	☐	☐	☐	☐	☐	☐
Ranking Position (i.e. 1st,2nd &3rd)	⬡	⬡	⬡	⬡	⬡	⬡

Comment freely---

THANK YOU!

Appendix.4.10

QUESTIONNAIRE ON THE SENSORY EVALUATION OF "MACARONI NOODLES" MADE FROM CASSAVA STARCH, DURUM WHEAT SEMOLINA AND THEIR BLENDS.

This study is for research purpose only. Please feel free to express your opinion on each of the samples.

Dear Mr/Mrs/Miss---------------------------- Date-------------

You are served with "**Macaroni Noodle**" samples to compare with reference sample '**R'**; signify your response for each organoleptic parameter on a five-point scale in terms of the selected parameters. Indicate the degree of difference in each box:

5 = Greatly superior to 'R'
4 = Slightly superior to 'R'
3 = Equal to 'R'
2 = Slightly inferior to 'R'
1 = Greatly inferior of 'R'

Parameters	Samples					
	301	*322*	*233*	*554*	*575*	*766*
Colour	☐	☐	☐	☐	☐	☐
Appearance	☐	☐	☐	☐	☐	☐
Firmness:	☐	☐	☐	☐	☐	☐
Stickiness	☐	☐	☐	☐	☐	☐
Chewiness:	☐	☐	☐	☐	☐	☐
Elasticity:	☐	☐	☐	☐	☐	☐
Taste:	☐	☐	☐	☐	☐	☐
Overall Acceptability:	☐	☐	☐	☐	☐	☐

Comment ---

THANK YOU AND GOD BLESS.

Appendix 4.11 Sensory evaluation in progress at IITA, Ibadan.