UTILIZATION OF SWEET POTATO STARCH, FLOUR AND FIBRE IN BREAD AND BISCUITS: PHYSICO-CHEMICAL AND NUTRITIONAL CHARACTERISTICS.

by

Anton Mais

A thesis submitted in partial fulfilment of the requirements for the degree of

Master of Technology in Food Technology

Massey University

2008

SUMMARY

UTILIZATION OF SWEET POTATO STARCH, FLOUR AND FIBRE IN BREAD AND BISCUIT: PHYSICOCHEMICAL AND NUTRITIONAL CHARACTERISTICS.

Sweet-potato contains a limited amount of protein, although rich in dietary fibre content and carbohydrate, so a successful combination with wheat flour for bread and biscuit production would be nutritionally advantageous. In particular, the role of these ingredients in relating to acceptability of breads and biscuit with higher percentage of sweet potato starch, flour in wheat flour. In this study, starch, flour and residue fibre of three sweet-potato varieties (red, orange and white -types) were studied. The 5 -10% combination levels for biscuit-making were found to be acceptable, without affecting the quality of the biscuit (combination of texture and biscuit size). In bread, bread containing 15% red and white replacement starches and orange replacement flour was found to be acceptable level, without affecting the quality of the bread, in an attempt to replace wheat at higher per cent level. The physicochemical study was complemented with a nutritional study to determine beneficial effects of food rich in dietary fibre and starches, in the context of improving diet related problems. RVA results showed sweet-potato ingredients affected differently the pasting temperature, peak viscosity and final viscosity of the normal wheat flour ($p<0.05$). Fibre inclusion showed large reduction in viscosity and swelling of sweet potato starch. Biscuits and breads containing sweet-potato starch and flour are low in amylose, and digest slowly because of lowly oriented and ‘crystalline’ areas within the granules enable to swell or to ungelatinised starch granules, whereas wheat control biscuit was able to gelatinised starch and exerted a greater effect upon digestibility. There are many other factors that need to be considered when analysing the in vitro starch digestibility such including amylose content, amylopectin structure and presence of fibre and gelatinising. Sweet-potato starch, flour and fibre addition show least effect on bread texture and size and starch, flour and fibre replacement. However, in *in vitro* starch digestibility test higher values RSS was recorded for starch addition followed by flour addition.

Table of Contents

List of Figures

List of Tables

Number *Page*

Acknowledgements

There are people whom I would like to thank who helped me in various stages of completing this thesis.

- Charles Brennan– my supervisor. Thank you for providing knowledge into the world of starch for which I have had no previous knowledge to any great detail. Thank you also for showing me how to use the various pieces of equipment required.

- New Zealand Development Agency (NZAID)-- my sponsor. Thank you for giving me extra time for completing my thesis. Thank you for providing much needed support and commitment.

1.0 Introduction

Sweet potato and cassava are the two major starchy crops used in tropical countries (Grace, 1977). Although, there is indeed growing evidence that starchy crops are essential components of diet of over 1 billion people in the tropical countries, they are characterized as traditional or subsistence food. According to FAO report (1984), 94% of world output accounted was from developing countries. In Papua New Guinea, sweet potato and cassava are most popular; however, the cultivation of these crops are done under small, scattered plots which much intercropping and shift cultivation that makes it difficult to assess their contribution to human food (Siki, 1979; Giheno, 1991). This is not surprising since a very small proportion of the third world are, root crop eaters, and very little research was done by them or funded by them. International bias in research and understanding away from root crops can only mean higher levels of food loss for the root crops growing countries and the purpose to achieve a threshold in the nutrition will be illusion.

The root and tuber crops are rich source of starch besides other minerals and vitamins, as they are often thought of as staples that provide high energy in diet (Bouwkamp, 1985; Wheatley and Bofu, 2000). In sweet potato, starch manufacturing is the main industrial utilisation due to its starch composition, and can be used in food application as major ingredient or as an additive depending on how it is used and cost of processing (Den, 1989., Chen *et al*., 2002; Chen, 2003).

In PNG alone, over 1.5 million dollars are spent each year on imported cereal grains, especially rice and wheat for bread-making and other cereal products. Bread is one of the most important sources of energy in diet from wheat flour. Although, bread is not a traditional dietary item in most developing countries, its consumption is rapidly increasing and utilisation of indigenous sources of starch such as sweet potato could lead to reductions in importation of wheat grain (Wanda, 1987; Bouwkamp, 1985; Hall *et al.*, 1992).

Current status of research in the processing of sweet potato primarily focus on two important components: physicochemical quality and processing of starch. From a food industry point of view physicochemical component is one of the most important factors that determine starch quality, which represents the uniqueness of crops in the starch applications (Chen, 2003; Moorthy, 2002). This includes ratio of amylose/amylopectin, molecular structure, granular size and inorganic constituents (Katayama *et al*., 2004). The quality of starch is affected mainly by the biological and environmental factors. These factors include genotype, soil types and climatic conditions, which are very different from one crop to another (Bouwkamp, 1985; Noka *et al*, 1995).

Less is known about the modification of starch in sweet potato, compared to cassava. A lot of work been done on fermentation of cassava and its effect on starch quality, whereas the use of enzyme in starch quality not been exploited (Jyoth *et al*., 2005). According to reviews done by Hoover (2001) and Moorthy (2002), it revealed that vast variation exits among roots and tubers species, which is not generally observed in the case of cereal starches. Because of the

importance of root and tubers crops in nutrition of food products, work is required on their physicochemical and nutritional properties.

Another important component is processing. Root crops have a large proportion of water and waste peel, which are transported to the final consumer; they are also perishable and there is inevitable marketing wastage (Bouwkamp,1985; Hall *et al*.,1992). Attempts have been made to process sweet potato into process forms. The most notable was the noodle production in Asia in mid 1940s – 1960s. It failed because it did not meet an acceptable standard (Chen *et al.,* 2002; Chen, 2003). But this kind of food can only come from new technology fanned by research and development activities.

Some significant work has begun to point up a number of potential applications for sweet potato to incorporate in new food products. The possibility of utilization of sweet potato and cassava starch in bread have been investigated in several other countries already, which include Egypt, Ghana, India, Israel, Korea, Philippines, Peru, Taiwan and Caribbean (Greene & Bowell-Benjamin*,* 2004).

According to Greene & Bowell-Benjamin (2004), the level of wheat flour substituting the sweet potato flour to produce consumer acceptable bread, in general, was to be between 10 – 15%. Substitution level of 20% produced bread unacceptable in terms of the loaf volume, flavour, and texture (Coursey *et al*., 1979). There has been no studies relating acceptability of breads with high percentage of sweet potato flour or combination of sweet potato flour and

whole - wheat to produce acceptable breads, however, bread containing 10 % sweet potato flour was desirable (Greene & Bowell-Benjamin, 2004).

Detailed work was expanded by some authors (Moorthy, 2002; Jangchud *et al.*, 2003., Rahman *et al*., 2003; Katayama *et al*., 2004) to study the quality aspects of sweet potato starch. From their investigations, starch composition quality: Total starch analysis, together with amylose and amylopectin composition were determined. It was been found that the ratio of amylose to amylopectin was 13-25% to 70–90%. Amylopectin affects the physicochemical properties of starch.

Starch pasting properties were evaluated using number of different viscosimeter, including Rapid Visco Analyzer (RVA), and Viscoelasticity profile was assessed using differential scanning calorimetry (DSC), nuclear magnetic resonance (NMR) spectroscopy and Brabender viscoamylography.

1.1 Literature Review

Sweet potato (*Ipomea batatas (L.) Lam*.) also known as kumara, is a very important crop in the developing world and a traditional, but less important crop in some parts of the developed world. According to the United Nation's Food and Agriculture Organisation (FAO) report (1984), sweet potato is one of the seven crops in the world which produce over 135 hundred million metric tonnes of edible food products in the world annually. Only potato and cassava, among the root and tuber crops, produce more. Of the total sweet

potato production in the world, 80-85 % is produced in China alone (FAO, 1984). The remaining countries in Asia have the next highest production and then followed by Africa and Latin America (Wanda, 1987).

The FAO statistics demonstrate the importance of sweet potato in the area where wheat production is often disadvantaged due to climatic restraints, wheat suitable for bread-making cannot be grown satisfactorily in many of these countries, and utilisation of indigenous crops could lead to reduction in importation of wheat or wheaten flour.

Apart from being a staple crop for some parts of the world (Papua New Guinea, some parts of Philippines, Tonga and Solomon Islands), sweet potato can, and does, play a multitude of varied roles in the human diets being either supplemental or a luxury food. In areas of Asia, sweet potato uses range from supplementary food of little status (Thailand) to a very important supplementary food (Ryukyu Islands, Japan) to rice and/or other root and tuber crops (Wanda, 1987). In the United States and other developed countries, the role of sweet potatoes is strictly as a luxury food and in other parts of the world (Japan) it plays it rote as novel plant products and/or nutriceuticals (Sosinski, 2002).

1.2 Nutritional Quality of Sweet potato

The nutritional qualities of sweet potato which are important in meeting human nutritional needs including carbohydrates, vitamins A and C, fibres iron, potassium, and high quality protein.

Because of the various roles that sweet potatoes play in around the world, the concept of nutritional quality and its contribution must transform to meet specific roles in human diet. For instance, staple type diets could require high vitamin C, iron, potassium, protein and as well as high fibre. Similarly, supplemental types of sweet potato must have many of the same characters as staple types in terms of nutritional components. However, as they will not be major food component, the level of components may be more flexible. For example, supplemental product could be acceptable with more sugar or vitamin A (carotene) than staple type. Luxury and nutriceuticals types of sweet potatoes are entirely different from the staple and supplementary types.

1.3 Some major components of sweet potato

1.3.1 Carbohydrate

Sweet potato can contain as much as 44% dry matter (Moorthy, 2002; Hoover, 2000). However, most commercial cultivars, especial in the US, contain 20-30% dry matter. According to Tsou et al. (1989), Asian Vegetable Development and Research Centre (AVDRC) had dry matter content ranging from 14 - 41% (Table 1.1). The major components of dry matter are carbohydrates which make up 90% of dry matter in most cultivars. The major carbohydrate components is starch, which in sweet potatoes, is 60-70% amylopectin and 30-40% amylose (Huo *et al*.,1985.; Chen *et al*., 2002; Moorthy, 2002; Hoover, 2001;). Sucrose is a major sugar in raw uncooked roots but glucose and fructose are also present; in cooked roots, major

products of starch conversion is maltose (Valetudie *et al.,* 1999; Thorne *et al*.,1983). The remainder of carbohydrates (primarily cellulose, hemicellulose and pectins) are collectively called fibre.

Table 1.1. Percentage mean and variation of major constituents of sweet potato

Constituents	Mean (%)	Variation (%)
Dry matter	29.87	14.99-41.98
Crude protein	4.22	1.34-11.08
Sugar	15.26	8.78-27.14
Starch	66.08	44.59-78.02
Crude fibre	3.99	2.70-7.60

Source: Tsou *et al* (1989)

1.3.2 Fibre content

The fibre content in sweet potato varies to a great extent depending on varietals variation and age of the crop, where the fibre content increases with the maturity. Wide variation in fibre and ash contents in different roots and tuber crops is evident from various reports by Bradbury *et al.* (1988 and 1989). Fibre content in flour derived from tuber extractions may vary to greater extent on the techniques and sieves, used for removal of the fibrous material. Sweet potato flour (containing 2-3% fibre) had different compositions compared to the isolated starch (having 0.1-0.15% fibre) (Moorthy, 2002).

Fibre is an important nutritional contributor of sweet potatoes in human diet. Potential benefits of soluble dietary fibre include reduction of bowel transit

time (Kelsay, 1988)., reduction in the rich of colorectal cancer, lowering of serum blood cholesterol, reduction of glucose metabolism and promotion of the growth of beneficial gut microflora (Welch & McConnell, 2001; Brennan, 2005)

1.3.3 Proteins

In sweet potato, the protein content is generally low, ranging from 1.0 to 14.2% dry weight basis (dwb) , with most levels ranging between 1.0 and 8.5% (Bradbury, 1989). The 14.2% as cited by Sosinski (2002) is exceptionally high. Sweet potato protein is of good quality and contains excess amounts of essential amino acids except tryptophan and total sulphur amino acids when compared with FAO reference protein (Wanda, 1987)

The low level of protein in sweet potatoes is a concern in the applications of food processing, has received much attention from breeders in areas where much of the genetic research is being conducted.

1.4 Starch

Starch occurs in plants as granules, which are characterised in size and shape for each plant source, and may be as small as 1-2 µm or as large as 100 µm. As the plant produce starch molecules, it deposits them in successive layers around a central hilum to form a tightly packed granule. As the layers of starch are not laid down uniformly about the hilum, most grains

have an eccentric form. Some grains typically have more than one hilum, whereas in others the position of hilum is difficult to determine. Again, their exact size however, depends on their source and the maturity of that plant source and may be spherical, oval or polygonal (Macmasters, 1964; Smith,1981). The small granules (called B-granules) are spherical shaped with a diameter below 10µm and large granules are called (A-granules) are lenticular with a diameter around 20µm (Moorthy, 2002, Chen, 2003).

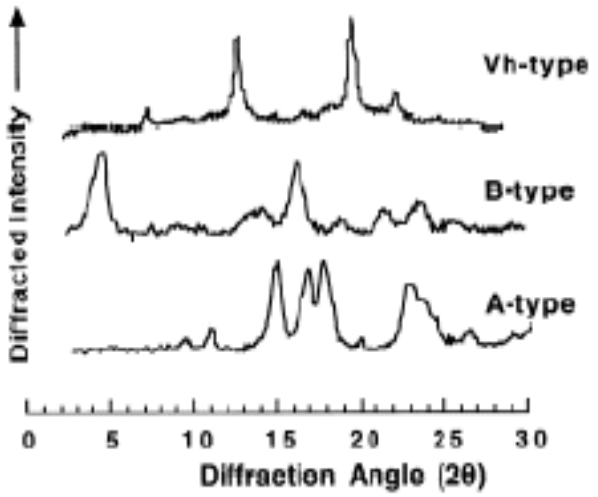


Figure 1.1: X-ray diffraction of 3 types of crystallinity in starch:• 'A' cereals. 'B' roots & tubers 'C' legumes, palms (**Source**: Moorthy 2002).

A starch granule consists of a semi-crystalline structure. The branches of amylopectin molecules are organised into double helices which are consisting of crystalline areas. Contrarily, amylose largely makes up the amorphous regions which are randomly distributed between the amylopectin cluster (Wang *et al*.,1998; Chen, 2003; Charles *et al.*,2005). The branched region

consists of the amorphous layer that separates the crystalline lamellae or crystallites from each other (Wang *et al*.,1998; Charles *et al*., 2005). X-ray diffraction showed that the crystallinity of wheat, maize, potato, waxy maize, and tapioca was in the range of 20-28% pointing out that the major part of the starch granules was amphous (Moorthy, 2002).

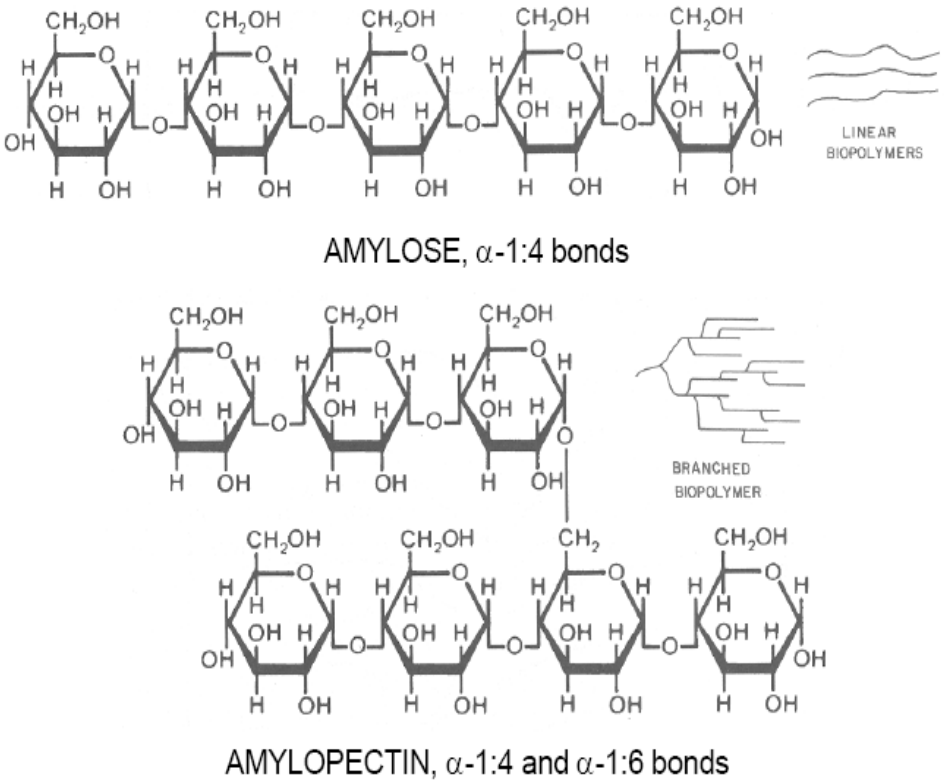


Figure 1.2: Structure of Amylose and Amylopectin (**Source**: Alais *et al* ., 1991)

1.4.1 Starch Composition

Starch is made up of amylose and amlyopectin according to their solubility in alcohol. The influence of amylose and amylopectin can be clearly seen microscopically. Under polarised light, the granules appear as bright, shinning objects on a dark background. Highly oriented and 'crystalline' areas within the granules enable ungelatinised starch granules to rotate the plane of

polarised light to produce characteristic interference or birefringence crosses. The intersection of these crosses is the position of the hilum. This birefringence cross is one of the features often used in identification of the source, and whether a starch has been heated sufficiently to gelatinise the granules. When the radial orientation of the crystalline area with the granules is disturbed, the birefringent cross disappears (Macmasters 1964; Smith, 1981).

Macmasters (1964) and Smith (1981), reported the amylose and amylopectin are different in their structure and properties, amylose contributes to the gelling property, while amylopectin give the high viscosity of paste and the ratio of these two polymers depend on the plant source.

According to Moorthy (2002) and Chen (2003), amylose is made up of glucose units in linear chain of linked with each other by hydrogen and hydrophobic bonds by α-1→4 linkages which forms a double helical structure. Amylose consists of chains containing many thousands of glucose residues (quoted chain lengths range from 200 to 5000 units).

Amylose is easily leached from swollen granules just above the gelatinisation temperature. Part of amylose can exist as soluble amylose in the amorphous regions of the starch granules. This fraction is easily leached out and hence considered responsible for cohesiveness in cooked tubers (Alais *et al*, 1991; Hoover, 2001; Moorthy, 2002).

Amylopectin generally have higher content of the glucose and is highly branched and is an amorphous polymeric structure containing 4 to 5% α-1:6 bonds at the branch points with an average side chain length of 20 to 25 molecules. They lack the general helical structure comparing with amylose as well as higher molecule weight up to 108, making it the largest molecule in nature. (Hoover, 2001; Nienke *et al*., 2004).

Amylopectin structure consists of three type chains: A, B, C type. The C-chain carries the sole reducing group in the molecule to which the B-chains are attached, while the terminal A-chain is attached to B chain. Because the polymer molecules exist as heterogenous mixtures, they are usually characterized by the average values of degree of polymer (DP) and “chain length” (CL) (Wang *et al.,* 1998; Zhang & Oates, 1999; Hoover, 2001: Chen, 2003). The CL distribution can be determined by size-exclusion chromatography (SEC) and high performance anion-exchange chromatography (HPAEC) with pulsed amperemetry detection after debranching of amylopectin with isoamylase or pullulanase. (Chen, 2003) The average CL of most amylopectins is in the range 18-24 (Katayama *et al.*, 2004). The A chain is shorter than B-chain. The ratio of A-chain to B-chain is the parameter in amylopectin characterization. Chen (2003) reported that the he most acceptable value of A/B ratio appears to be 1.0 -1.4:1. A high proportion of A-chain gives a low tendency to retrogradation of amylopectin.

Most cereal starches (e.g. normal corn, rice, wheat and oats) display type A, while tuber starches (potato, arrowroot and tulip) exhibit the B type. The C

type is the mixture of A and B type. Several rhizome and bean starch belong to the C type (Hoover, 2001; Chen, 2003; Charles *et al*., 2005). Some important physicohemical properties properties of amylose and amylopectin are found in Table A.1 , Appendix A on page 162.

1.5 Starch quality determination

One of the most important contributing factors that determine starch quality from food industry point of view is the physicochemical components, mainly the gelatinisation and pasting behaviour which represents the uniqueness of crops in the starch applications (Chen, 2003; Moorthy, 2002).

The quality of starch is affected mainly by biological and environmental factors. These factors include genotype, soil types and climatic conditions, which are very different from one crop to another (Noka *et al*., 1995; Bouwkamp, 1985; Katayama *et al*., 2002).

1.5.1 Gelatinisation

Gelatinisation is the transformation that occurs when an aqueous starch suspension is heated. The process involves a loss of granule crystallinity by disruption of granule structure as gauged by a loss of birefringence, hydration and slight swelling of the granule, and the change is irreversible (Macmasters, 1964; Smith, 1981).

Continued heating above the gelatinisation temperature results in the granules becoming highly hydrated and their volume increasing to many times their original. Starch granule swelling in water is a reversible process at temperature below the gelatinisation temperature due to its stable semi-crystalline structure (Hoover, 2001; Chen, 2003). According to Chen (2003), the water absorption is usually less than 40%. When the temperature of granules in water increases to the gelatinization temperature (50-85˚C) the starch granules will lose its birefringence and crystallinity, with concurrent swelling.

1.5.2 Retrogradation

Starch granules when heating in excess water above their gelatinisation temperature, the linear structure cross-bond and increases starch stability ((Macmasters, 1964; Smith, 1981). It reinforces hydrogen bonding of starch-to-starch chain with covalence chemical bonding. During cooling (storage) starch pastes may become cloudy and eventually deposit an insoluble white precipitate. This is caused by the recrystallinization of starch molecules; initially the amylose forms double helical chain segments followed by helix-helix aggregation (Zhang *et al.,* 1999; Hoover, 2001; Moorthy, 2002; Chen *et al*., 2002). The starch transformation at different stages of processing is as shown in the Figure 2.6. Amylose is considered primarily responsible for the short-term retrogradation process due to the fact that the dissolved amylose molecules reorient in parallel alignment. The long-term retrogradation is represented by the slow recrystallinization of the outer branches of

amylopectin. The recrystallised amylopectin in the retrograded gel can be melted at 55, whereas for the recrystallized amylose the melting temperature rises to 130˚C (Hoover, 2001: Moorthy, 2002).

The rate and the extent of retrogradation increase with an increased amount of amylose (Moorthy 2002; Chen, 2003). In addition to the original of starch, retrogradation also depends on the starch concentration, storage temperature, pH temperature procedure and the composition of the starch paste.

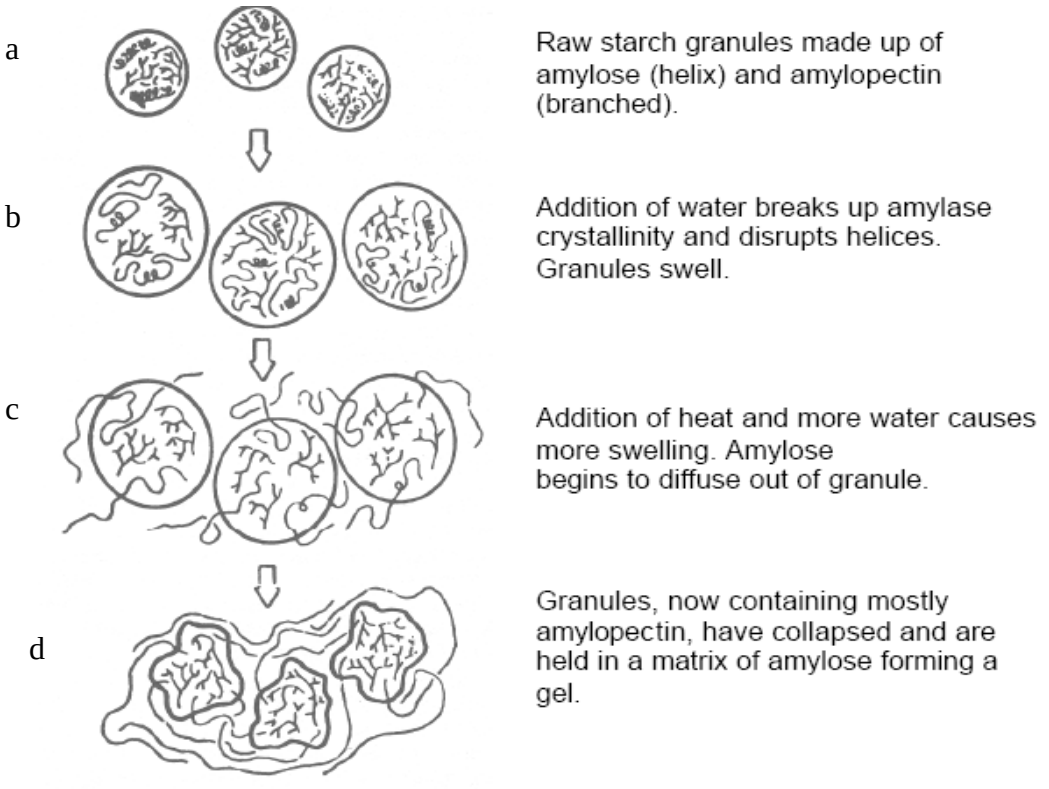


Figure 1.3: Fundamental transformation stages in processing of starch. a) loss of crystallinity, double helical order and uptake of heat, b) granules hydrate and swollen, c) amylose leached out , d) forming gel (**Source**:Baianu, 1992).

1.5.3 Starch functionality

In food industry, starch has been widely used for Many years at moderately low levels as an ingredient that has both nutritive value and is able to simultaneously impart functional properties to food system. It may be used for a variety of purposes in a food system, to facilitate processing, to provide texture, for thickening, the suspension of solids, the protection of foods during shipment or processing etc. many of the quality attributes of foods can be modified or influenced by the starch present. In addition to their wide availability, food starches can be chemically, physically or enzymatically modified in order to meet specific requirements for food systems (Macmasters, 1964; Smith, 1981).

1.6 Properties of sweet potato starch and their influence upon processing

The properties of sweet potato starches, particularly rheological properties and pasting behaviour, have been the subject of several investigations. The data of starch functionality of sweet potato and other tropical roots-tubers had been reviewed by Moorthy (2002) and Nienke *et al.,* (2004), is useful to predict behaviour of starch under processing conditions. According to the rheological assessment of sweet-potato starch-water paste studied (Osundahunsi, 2003; Jangchud *et al.,* 2003; Greene & Bowell-Benjamin, 2004), sweet potato starch possess a rigid viscous behaviour and lower gel strength. Most of the yam starches possess characteristics of very viscous

pastes with high gel strength compared to sweet potato and other tropical root starch (Rasper 1979, Lauzon *et al.,* 1995). According to data obtained from the studies, these rheological characteristics can be related to their swelling and solubility properties of the starch, and also their granular size. Swelling and solubility of sweet potato starch are less than those of cassava (Moorthy, (2002). The gelatinization characteristics of sweet-potato, together with various other roots and cereal starch, are given in Table 1.2.

Table 1.2: Gelatinisation characteristics of sweet-potato and other starches

Origin of Starch	Pasting Temperature[a] °C	Maximum Viscosity[a] (B.U.)	Period of Increasing Viscosity[a] min	Apparent Rate of Viscosity Increase	At 95°C	
					Swelling Power	Critical Concentration Value
Root starches						
Potato (Solanum tuberosum)	62.5	1920	8.0	0.4	>100	<1
Cassava (Manihot utilissima)	63.5	690	12.5	1.8	48.7	2.6
Cocoyam (Xanthosoma sagittifolium)	77.0	350	2.5	0.8	30.9	3.2
Sweet potato (Ipomoea batatas)	77.0	590	5.0	0.9	27.2	3.7
Yam (Dioscorca)						
D. rotundata	73.5	980	22.5	2.3	24.9	4.0
D. esculenta	78.5	500	steadily increasing		23.0	4.3
D. cayenensis	75.0	690	16.5	2.4	21.3	4.7
D. alata	77.5	620	steadily increasing		18.3	5.5
D. dumetorum	83.0	185	"	"	13.9	7.2
Colocasia (Colocasia antiquorum)	77.0	260	"	"	16.0	6.3
Alocasia (Alocasia macrorrhiza)	73.0	160	"	"	16.6	6.0
Cereal starches						
Maize	79.5	265	9.0	3.4	16.5	6.1
Other starches						
Plantain (Musa paradisiaca)	75.5	530	15.0	2.8	22.1	4.5

Source: Coursey *et al*., (1979)

The pasting behaviour of sweet-potato starch exhibits high peak viscosity and becomes thinner rapidly with prolonged cooking before thickening on cooling (Moorthy, 2002**;** Jangchud *et al*, 2003). Comparing with yam starch, which shows absence of peak viscosity (which indicate heat stability) when starch is subjected to heating its: the very slow viscosity, rather, increases through the heating and cooling cycles (Coursey *et al*, 1979, Moorthy, 2002).

The desirable gluten-free dough-like texture of pancake from rice and sweet-potato is a transient characteristic which fades rapidly under normal holding conditions (Shihh *et al*., 2006). This decline in quality has been attributed to starch retrogradation (Coursey *et al.,* 1979; Valetudie et al 1995). Those authors followed the changes in the rheological properties of the dough after preparation by means of compression tests, and x-ray diffraction studies. The low degree of retrogradation observed in yam starch was also noted by Rasper (1969) and Vantetudie *et al*., (1995, 1999); Moorthy, 2002). It is suggested that high content of amylose in the starch is responsible for high degree of retrogradation property (Coursey *et al*.,1979; Zhang *et al.,* 1999). However, Macmasters (1964) and Moorthy (2002), cited that the wide range in values indicates that the retrograded starch contains recrystallised amylopectins of different crystallinity.

The resulting changes, wherein the dough loses its elasticity and becomes hard and brittle due to the growth crystals in the dough structure upon retrogradation, are temperature dependent (Coursey *et al*., 1979), increasing with decreasing storage temperature down to 2°C (Juarez-Garcia *et al*.,2006).

The rate of retrogradation of sweet potato starch is several times slower than the wheat starch or corn but similar to potato (Moorthy, 2002,). This process being virtually complete at 20°C in yam starch dough after 12 hours, compared with 16 days for wheat starch gels (Shiraishi *et al*., 1995). Further studies of this phenomenon on sweet potato starch are desirable, as their results could lead to some means of retarding these undesirable changes.

Most of the sweet potato starches have been shown to possess gelatinisation temperatures in the range between 54-84°C (Chen, 2003; Hoover, 1992; Moorthy, 2002; Jangchud *et al.,* 2003). However, when compared to with other tropical root starches, gelatinisation temperature of sweet potato is not as high as cassava and yam (Opêna, 1987; Moorthy, 2002), and possesses low susceptibility to digestibility by α-amylase emzyme (Zhang *et al.,*1999; Moorthy ,2002). This relative resistance of sweet potato starch to digestive enzymes was found in most tropical root starch, with noticeable exception of cassava starch (Rasper, 1969) and may be of importance in determining functional properties of sweet potato starch in composite doughs.

1.6.1 Comparison of starch and flour of Sweet potato

The information of sweet potato starch pasting behaviour is not same as those of sweet potato flour. According to Moorthy (2002) and Jangchud *et al* (2003), sweet potato starches exhibited the a-type (high swelling) pattern. The granules of starches swelled enormously when cooked in water as shown by the sharp pasting peak, and then the internal bonding forces became tenuous

and fragile toward shear forces as shown by the rapid and major thinning during cooking.

Furthermore, Jangchud *et al*., (2003) suggested that most of the pasting parameters of the sweet-potato flour were not significantly correlated to the pasting parameters of the purified starch. Hence, the pasting profile of the flour cannot be used to indicate the pasting properties of the starch (Greene & Bowell-Benjamin, 2004). The degree of starch gelatinization from fresh mixtures of sweet potato flour was found to be 50%. This indicates that processing the flour partially gelatinizes the starch (Hall & Bonsi, 1992). Moorthy (2002) mentioned a gelatinization temperature between 74 –78°C, and Jangchud *et al*.,(2003) found a pasting temperature of 61- 79°C.

1.7 Analysis Techniques

In order to examine the starch-based products for the effect of the different levels of sweet-potato flour and starch on wheat-flour, two experimental techniques will be employed. These techniques are Rapid Visco Analysis (RVA) and the compression test.

1.7.1 Rapid Visco Analyser (RVA)

RVA is for the testing of the pasting behaviour of various foods and other products. It performs at various stages of pasting behaviour. There is usually an inverse relationship between viscosity and temperature, a direct nonlinear

relationship between the concentration of a solute and the viscosity (at constant temperature), a direct nonlinear relationship between the molecular weight of the solute and the viscosity of the solute at equal concentrations. Suspended matter usually increases the viscosity slightly when in low concentrations, but high concentrations of suspended matter can cause substantial increases because of entanglement between the particles (Truong *et al*., 1986). There are many factors that affect pasting behaviour. These factors include temperature, concentration of solute, molecular weight of solute and suspended matter.

There are various types measurement devices for measuring starch paste viscosity, it is essential that the temperature be closely controlled, as the viscosity of fluids is highly temperature dependent. Hence, the temperature at which viscosity measurements were taken should be stated with all viscosity data because the data are meaningless unless the temperature is known. The different types of viscometers include x-ray diffraction, DSC, barbender amylography and other viscometers, are classified according to the principle on which they work. The starches of three sweet potato species of Thailand were studies by Jangchud, *et al.* (2003). Those authors reported the gelatinization and pasting properties of starches could be studied using different analytical techniques such as differential scanning calorimetry (DSC), nuclear magnetic resonance (NMR) spectroscopy and Brabender viscoamylography.

The Rapid Visco Analyser (RVA) is another rotational viscometer and employs a paddle that rotates in a container. The RVA is mainly used for testing viscous properties of starch slurries. The rotation of the paddle maintains homogenous suspension of the starch granules prior to gelatinisation. The paddle sensor is usually used for testing samples in the RVA. The RVA sensor is not geometrically defined to give a single shear rate and stress is not possible by fundamental means, is highly empirical hence lack of detailed mathematical analysis (Mohsein, 1980). Starch-based pastes or gels are typically non-Newtonian where a reduction in viscosity is usually observed with both increases in shear stress (pseudoplastic flow, or shear thinning) and increases in time (thixotropy). The degree of non-Newtonian behaviour varies considerably between certain starches, or even for the same starch under different cooking conditions.

1.7.2 Compression Test

The compression Test is a method of testing the textural properties of foods. Texture, appearance and flavour are the three major components of food acceptability (Truong *et al*., 1986). Characterisation of the textural properties of foods commonly falls into two main groups, based on sensory and instrumental methods of analysis. However, it is sometimes preferable to use the instrumental method of analysis as the analysis is conducted under more strictly defined and controlled conditions, and hence the variability resulting from the sensory analysis can be avoided (Staley,1989).

Instrumental texture analysis is the analytical procedure that subjects a sample to known conditions (stress or strain) in a controlled manner from which mechanical characteristics can be determined (Mohsenin,1980). Stress is the measure of force concentration on a material. Most applications of textural analysis investigate normal stresses (as opposed to shear stresses), which are the stresses that act in a direction perpendicular to the surfaces of the material they deform. The advantage of defining the stresses of a material, as opposed to the forces, is that stresses characterise the ability of the material surfaces to respond to external forces, independently of sample size or shape. This property is essential for determining the rheological properties of a material (Mohenin, 1980).

Uniaxial stress may be tensile or compressive. However, compression is the type of test most frequently used by food technologists. This test is used to imitate the biting/chewing action of the mouth, a process known as mastication. In the human body, the forces exerted by the teeth provide the stress on the food while the movement of the jaw provides the strain on the food during mastication (Adihikari *et al*., 2001).

The bending and snapping test is one method of performing fracture and hardness tests. The bending and snapping test involves a sample of food, usually in the shape of a bar or sheet, resting on bottom support ring while a compressing probe moves down the centre of the support ring pressing the food until it snaps. The compression test is another method that could be used to test for hardness, while allowing cylinder probe moving down the

centre of a heavy platform to pressing the food at 20 per cent of the food thickness and allows measurement of bread firmness according to AACC Standard method 74-09 (Brennnan & Samyue,2004).

1.8 Sweet-potato flours used in composite flour for bakery products

Sweet potato flour cannot be used totally for bread production. Coursey *et al*., (1979) reported that, an attempt at total substitution of wheat flour by root crop flours in bread, in which various starch binders were incorporated to maintain loaf volume in the absence of gluten, and of protein additives to sweet potato flour, were investigated, resulting in poor loaf volume, meaning that total substitution is likely to be more successful with baked goods only rather other than bread.

Investigation by Substitution (Coursey *et al*., 1979) on wheat flour by yam flour at the 15 percent level in bread has been shown to give a satisfactory product, while with other root-tubers such as potato, were even higher levels (50 and even 55% percent) depending upon potato varieties.

Greene & Bowell-Benjamin, (2004) conducted a study on sweet potato flour and found that the level of wheat flour substituting the sweet potato flour to produce consumer acceptable bread, in general, was to be between 10 – 15% (Substitution level of 20% produced bread unacceptable to in terms of the loaf volume, flavour, and texture). This work was further extended by the same author (Greene & Bowell-Benjamin, 2004) has shown bread containing 6 – 8% sweet potato flour is feasible.

1.9 Carbohydrate metabolism and dietary fibre

In most developed countries, consumer attention has recently focused on low-calorie food products, with emphasis being placed on healthy eating and increased fibre within a balanced diet (Brennan and Samyue, 2004). Integration of wheat flour and sweet potato enhance the fibre content of bread and may have a significant effect on human health. The consumption of more dietary fibre may be a beneficial step towards a balanced nutritional diet. The current recommendations suggested an intake of 20-40 g dietary fibre (Brennan, 2005)

An investigation of cereal grains contains phytic acid, which can bind minerals conducted on humans, complicates the interpretation of effect of fibre from grains (Kelsay, 1987). That was done after a concern that due to the ability of fibre to bind minerals, mineral bioavailability may be decreased when fibre in the diet is increased. According to the author (Kelsay, 1987), the residue of carrot (38g/day) and cabbage (35g/day) increases stool weight more than did wheat bran (40g/day). This was supported by Stephen and Cummings (1980), that when the subjects consumed cereal bran, there was a greater increase in faecal bowel than with cabbage. In some studies results have shown that an increased intake of fibre results in increased of faecal loses of energy, fat, nitrogen.

Fibre can also have an impact on food by reducing the rate of glucose breakdown and absorption, hence avoiding an excess of glucose in the body

and facilitating the steady breakdown of carbohydrates and release of glucose (Brennan, 2005).

Carbohydrates are an important source of energy as mentioned in 2.21. However the role of carbohydrate metabolism in nutrition is the cornerstone of the our regulation of energy intake and body weight maintenance. Complex carbohydrates, (starch) are metabolised by our body into their monosaccharide constituents that play their part in nutrition, glucose metabolism and absorption (Brennan, 2005).

1.10 Effect of starch on starch Digestibility

A number of investigations and reports on characteristics of α-amylase action on sweet potato starch granules were reported by Walker, (1975) and Zhang *et al*. (1999). These investigations have shown that starch varied in their resistance to the action of α-amylase.

In nutritive value and also in industrial applications, digestibility of starch by α-amylase enzyme is important for evaluating food products. Starch hydrolysed in the *in vitro* system, is considered as carbohydrate availability completely digested and absorbed in the small intestine (Asp & Bjorck, 1992; Brennan, 2005). The work of *in vitro* digestibility of starch system by Jeffrey and co-workers (Thorne *et al*., 1983) have shown this concept and, relates the evaluation of *in vitro* as useful for predicting the likely glycaemic response to foods, a nutritional classification of food.

Zhang and Oates (1999) cited studies from various people on factors that affect the starch digestibility, such as amylose and amylopectin, crystalline structure, present of enzyme inhibitor and particle size. Furthermore, Thorne and co-workers (1983) reported that the nature of starch in food could be seen as another factor affecting digestibility when testing different starchy food and found that this related to differences in digestibility of the different starch and not related to dietary fibre content of the food. At that time much attention was focused on dietary fibre hypothesis (Thorne *et al.*, 1983), which had led to demonstrate that fibre altered the rate of nutrients adsorption in the gastrointestinal tract.

In view of this, Zhang and Oates (1999) reported undertaking a study on six sweet potato starches and their relationship between physicohemical properties and susceptible to α-amylase attack and found that susceptibility to amylase was influenced by starch granular structure such as amylose and amylopectin ratio (high amylopectin vs low amylose) and their molecular association.

It is possible that an interaction between protein and starch in food influences the digestibility and glycaemic index response to starch and evidence of this hypothesise was acknowledged by Thorne *et al.* (1983).

Many intrinsic and extrinsic factors in starchy foods, such as dietary fibre, nature of starch, amylose ratio, time of processing, physical form and nature of starch (Truong *et al*., 1986; Asp & Bjorck, 1992, Vosloo 2005; Brennan,

2005) interfere in the digestion and absorption of starch and explain the foods ranking observed in the glycaemic index tables (Table A.2, Appendix A, on page 163)

1.11 Aim and outline of the thesis

Information provided in the literature review has shown the complexity of classifying starch quality of tropical starchy crops, although bread-making sweet potato flour quality has been studied thoroughly by numerous researchers. In order to investigate and understand the factors that impact on sweet potato functionality as well as to provide the consumers with acceptable products, there still remain areas of research needed to relate sweet potato quality to specific end uses such as bread-making and or other bakery products.

The aim of this research is to study the physiochemical properties of sweet potato tubers and its isolated components such as flour, starch and fibre (non-starch) derived from three commercial varieties and to compare these ingredients on starch degradation rate and extend of hydrolysis with wheat flour as reference. Sweet potato starch and it isolated components will be studies for their ability to improve bread quality by replacing wheat flour at 5%, 10% and 15% levels or by adding sweet potato ingredients without altering the bread formulation(s).

A pasting model for sweet potato starches used in composite mixture is presented in chapter 4.

Chapter 2 described the effect of different starch ingredients and quality on end use product and development of dietary enriched biscuits. Sweet potato biscuit made from three commercial varieties and their relationship between their physicochemical properties and starch susceptibility to α-amylase attack is described in chapter 3. The quality of starch dough and biscuit made from sweet potato at 5 and 10 percent level of replacement was much more suitable than those at 15 percent level of replacement. Fibre addition showed drastic effect on biscuit thickness and fracturebility (Chapter 3).

Chapter 5 described investigate into sweet potato bread-making and understand the quality and physio-chemical reactions that occur during baking that are related to the functional properties of starch. At the same time focused on starch degradation and on components that influence the rate of digestion in starchy foods. The 3 sweet potato varieties (orange, red and white fleshed skin) were tested to substitute commonly used wheat flour. The wheat flour quality and effects of the replacement and addition of sweet potato on composite flour are described in chapter 5. Finally, in the concluding remarks an overview of this research work and further discussion is given (Chapter 7). Ways to apply starch and derivatives in future sweet potato bread production are suggested.

1.12 REFERENCES

Adhikari, B., Howes,T., Bhandari, B.R., and Truong, V. (2006). Stickiness in food: A mechanism and test methods, International Journal of Food Properties, 4 (1), 1-33

Alais, C., Linden, G. (1991). Food chemistry, Ellis Horwood series in food science and technology press. New York, USA

Asp, N-G & Björck, I. (1992). Resistant starch. *Trends in Food Science and Technology* 3(3):111-114.

Baianu, C. Ion (1992). Physical chemistry of food process, fundamental aspect, **1**, New York Van Nostrand Reinhold , pp 104-105

Bouwkamp, J.C., (1985). Sweet potato products: a natural resource for the tropics, Boca Raton, Fla. : CRC Press, Florida, USA

Bradbury, J. Howard, (1989). Chemical Composition of cooked and uncooked sweet potato and its significance for human nutrition. Mackay, Kenneth., Palomar, Manual., Sanico, Rolinda (editors). Sweet potato research and development for small farmers, SEAMEO-SEARCA, Philippines, pp 213-225

Bradbury, J.H and Holloway, W.D., (1988). Chemistry of Tropical root crops: significance for nutritional and agriculture in the pacific, Australian Centre for International Agricultural research, Canberra, Australia, pp 51

Brennan, S .Charles, 2005. Dietary fibre, glycaemic response, and diabetes. Molecular Nutrition*. Food Resource* **49**, 560 – 570

Brennan, C.S & Samyue, E. (2004). Evaluation of starch degradation and textural characteristics of Dietary fibre-enriched biscuits. *International Journal of Food Properties*, **7**(3): 647-757

Charles, A. L., Chang, Y. H., Ko, W.C., Sriroth, K., Huang, T.C., (2005). Influence of amylopectin structure and amylose content on the gelling properties of five cultivars of cassava starches, Journal Of Agricultural and Food Chemistry, **53** (7): 2717-2725

Chen, Z., Sagis, L., Legger, A., Linssen, J.P.H., Schols, H.A., (2002). Evaluation of starch noodles made from three typical Chinese sweet-potato starches, Journal of Food Science **67** (9): 3342-3347

Chen, Z (2003). Physicochemical properties of sweet potato starch and their application in noodles, PhD Thesis, Wageningen University, The Netherlands http://library.wur.nl/wda/dissertations/dis3450.pdf

Coursey, D.G., Ferber, C.E.M., (1979). The processing of yams. Plucknett L.D (Editor). Small-scale processing and storage of tropical root crops westview Press, Colorado, pp 189-211

Den, Truong Van (1989). New development in processing sweet potato for food. Mackay, Kenneth., Palomar, Manual., Sanico, Rolinda., (Editors). Sweet potato research and development for small farmers, SEAMEO-SEARCA, Philippines, pp 213-225

FAO Publication Yearbook (1984), Food and Agriculture Organisation, Rome Italy, vol **38**,

Giheo, J (1991). Medium term industry and trade development action plan. Part A: Strategy, Policies and Programme. Government of Papua New Guinea, Ministry of Trade and Industry

Grace, M.R (1977). Cassava processing, FAO Plant production and protection series no.3, Rome, United Nation Press

Greene, J.L., Bovell-Benjamin, A.C. (2004). Macroscopic and sensory evaluation of bread supplemented with sweet potato flour, Journal of food science **69** (4):167173

Hall,W.A., Bonsi, C.K, (1992). Sweet potato technology for the 21st century, Alabana, USA Tuskegee University , Ecology of Food and Nutrition **40** (4): 367-395

Hoover, R. (2001). Composition, molecular structure, and physicochemical properties of tuber and root starches: a review, Carbohydrate Polymers **45** (3): 253-267

Huo, G., Lin, S and. Green, S., (1985). Sweet potato germplasm for international cooperation. International Cooperation's Guide, AVRDC , pp 85- 238

Jangchud, K., Phiimolsiripol, Y., Haruthaithanasan, V. (2003). Physicochemical properties of sweet potato flour and starch as affected by blanching and processing, Starch-Starke **55**: 258-264

Jyothi, N. A., Wilson, B., Moorthy, S., George, M. (2005). Physicochemical properties of the starchy flour extracted from sweet potato tubers through lactic acid fermentation, Journal of the science of Food and Agriculture **85**: 1558-1563

Kartayama, K., Tamiya, S., Ishiguro, K. (2004). Starch properties of new sweet potato lines having low pasting temperature, Starch-Starke **56** (12): 563-569

Katayama, K., Komaki, K., Tamiya, S, et al. (1999). Varietal and annual variations in pasting properties of sweet potato starch , Breeding Science **49** (3): 173-178 SEP 1999

Kelsay, June L (1987). Effect of fruit and vegetables fibre consumption on Nutrition Bioavailbility, Quebedeaux, B and Bliss, F (Editors). Proceedings of the first international symposium on horticulture and human nutrition. Contributor of fruits and vegetable, Prentice Hall, pp 80-89

Juarez-Garcia,e. , Agama-Acevedo, e. , Sáyago-Ayerdi, S.G. , Rodríguez-Ambriz, S.L. and Bello-Pérez, L.A. (2006). Composition, digestibility and application in breadmaking of banana flour*. Plant Foods for Human Nutrition* **61**: 131-137

Lauzon, Rd., Shiraishi, K., Yamazaki, M, et al. (1995). Physicochemical properties of cocoyam starch*, Food Hydrocolloids* **9** (2): 77-81

Macmasters, M.M. (1964). *Methods in Carbohydrate Chemistry*. Whislter RL, editor. Academic Press. P.233

Mohsenin, N , Nuri (1980). *Physical properties of plant and animal materials: Structure, physical characteristics and ,mechanical properties*. Gorden and Breach Science Publishers, Inc. New York, pp 174-305

Moorthy, S. N. (2002), Physicochemical and functional properties of tropical tuber starches: A review, Starch-Starke **54** (12): 559-592

Nienke, L., Peter, R.C., Robert, T.T. (2004). Analytical, Biochemical and Physicochemical Aspects of Starch Granule Size, with Emphasis on Small Granule Starches: A Review**,** Starch - Stärke **56** (3-4**):** 89-99

Noda, Y. Takahata, T. Sato, H. Ikoma, H. Mochidas, (1995). Physicochemical properties of starches from purple and orange-fleshed sweet potato roots at two levels of fertilizer. *Starch/Stärke* ***48***, 395-399.

Oladiran, O. F., William, M. W., Henry, P.F and Nada, S. (2003). Viscoelastic properties of restructured sweet potato puree**,** International Journal of Food Science & Technology **38** : 421-427

Opêna, R.T., Takagi, H and Tsou, S.C.S (1987). AVRDC Sweet potato improvement program. Paper presented in the International Sweet potato workshop, ViSCA, Philippines , pp 20-25

Osundahunsi, O.F., Fagbemi, T.N., Kesselman, E., Shimoni, E. (2003). Comparison of the physicochemical properties and pasting characteristics of flour and starch from red and white sweet potato cultivars, Journal Of Agricultural And Food Chemistry **51** (8): 2232-2236

Rasper, V (1969). Investigations on starches from major starch crops grown in Ghana:. Particle size and particle size distribution Part II: *Journal of Science Food Agriculture* **20**, pg-642

Rahman, S.M.M., Wheatley, C., Rakshit, S.K. (2003). Selection of sweet potato variety for high starch extraction , International Journal Of Food Properties **6** (3): 419-421

Shiraishi, K., Lauzon, R.,Yamazaki, M., Sawayama, N (1995). Rheological properties of cocoyam starch paste and gel, Food Hydrocolloids **9** (2): 69-75

Shih, FF, Truong, VD, and Daige KW (2006). Physicochemical properties of gluten- free pancake from rice and sweet potato flours Journal of Food Quality 29 (1), 97–107

Siki BF (1979), Processing and storage of roots crops in Papua New Guinea. Plucknett LD (Editor). Small-scale processing and storage of tropical root crops westview Press, Colorado pp 64-82

Smith, P.S. (1981) in Food Carbohydrates D.R. Lineback and G.E. Inglett (Eds.) AVI Publishing, Connecticut.

Sosink, B; He, J. Cervantes-Flores, R.M Pokrzywa, A Bruckner and G.C. Yencho.(2001). Sweet potato genomics at North Carolina state university. Ames, T (Ed), Proceedings of the first international Conference on sweet potato. Food and Health for the Future, Acta Horticulture 583: pp 69-76

Staley, A.E, (1989). General Method for testing starch. *Applications manual for the Rapid Visco Analyse*r, New port Scientific, New South Wales, Australia, pp 20 –21

Truong, Van Den, Christopher J, Biermann, and Judith, A Marlett. (1986). Simple Sugars, Oligosaccharides, and starch concentration in raw and cooked sweet potato. Journal of Agric Food Chemical 34: pp 421—425

Tsou, Samson C.S., Kan, Kuang_Kung.,Wang, Shu_Jen (1989). Biochemical studies of sweetpotato for better utilisation at AVRDA. Mackay, Kenneth., Palomar, Manual., Sanico, Rolinda (editors). *Sweet potato research and development for small farmers*, SEAMEO-SEARCA, Philippines, pp 213-225

Stephen, AM, Cummings JH (1980). Mechanism of action of dietary fibre in human colon. Nature 284: pp 283-284

Thorne, Mary Jane., Thompson, Lilian U and Jenkins, David J. A, (1983). Factors affecting starch digestibility and the glcemic response with special reference to legumes. The American Journal of clinical nutrition **38**, pp 481-488

Valetudie, J.C., Gallant, D.J., Bouchet, B, et al. (1999). Influence of cooking procedures on structure and biochemical changes in sweet potato, Starch-Starke **51** (11-12): 389-397

Valetudie, J.C., Guadeloupe, L., Colonna, P, et al.(1995). Gelatinization of sweet-potato, tania and yam tuber starches, Starch-Starke **47** (8): 298-306

Vodoo, M. Charlyn, (2005). Some factors affecting the digestibility of glycemic carbohydrate and blood glucose response, Journal of Family Ecology and Consumer Science **33**, , pp1-9

Wanda, Collins W. (1987), Genetic improvement for meeting human Nutrition needs. Quebedeaux, B and Bliss, F (Editors). Proceedings of the first international symposium on horticulture and human nutrition, Contributor of fruits and vegetable, Prentice Hall, pp 191- 199

Wang, L.T., Bograchava, T.Y., Hedley, C. (1998). Starch: as simple as A,B,C: Review, Journal of Experimental Botany, **49** (320): 481-502

Walker, W.M., Purcell, A.E and Nelson, A.M. (1975). Effect of amylotytic enzymes on moisture and carbohydrate changes of baked sweet potato cultivars. Journal of Food Science **40**: 793-796

Wheatley, C.C., Bofu, S. (2000). Sweetpotato starch in China: status and future prospects. Peru. International Potato Center (CIP), 4pg

Zhang, T., Oates, C.G. (1999). Relationship between alpha-amylase degradation and physico-chemical properties of sweet potato starches, Food Chemistry **65** (2): 157-163

2.0 Materials and Methods

2.1 Materials

Three types of kumara tubers, red, orange and white flesh colours were obtained from a local supermarket in Palmerston North, New Zealand. High-gluten baking flour (Wheat flour A Grade, Goodman Fielder, NZ) was used as reference and purchased from the supermarket in Palmerston North.

2.2 Starch extraction

Starch was extracted from tubers using a slight modification of the method of Whistler *et al.* (1964), where sodium metabisulfite was used with distilled water. Tubers were manually peeled, cut into 4-6 cm pieces, soaked in 0.2% sodium metabisulfite for 5 min, and the juice was extracted using a Breville juicer (Juice Foundation, Australia) at a low speed for 5 min. The resulting starch slurry was filtered through a screen (200 micron) and then passed again through a 100-micron screen. The filtrate was collected and allowed to stand undisturbed for 1 h. The white starch fraction was collected, resuspended in distilled water, and allowed to settle. This process was repeated three times to eliminate sulphite residues. The collected starch was oven-dried at 40 ºC for 24 h, finely ground using a coffee grinder, sieved through a 120-micron mesh sieve, packaged in polypropylene bags, and stored at room temperature until further analyzed. Three batches of starch of each of the tubers of different colours were prepared, and the starches of the separate colours were pooled to produce orange starch (OS), red starch (RS) and white starch (WS).

2.3 Sweet potato flour extraction

Flours were prepared according to the method of Plunnett (1979) with a slight modification. Roots were manually peeled, sliced into 2-mm thickness, soaked in 0.2 % potassium metabisulfite for 5 min using motor-operated slicer (Sama, France), dried on a meshed wire tray at 40 ºC for 24 h, finely ground using a laboratory hammer mill (Siemens-Schuckrt, Germany), and sieved through a 300-micron sieve to produce uniform-sized flours. Three batches of sweet-potato flour varieties were prepared. The flours were assigned names, orange flour (OF), red flour (RF), and white flour (WF), packaged in polypropylene bags and stored at room temperature until further analyzed.

2.4 Residue fibre extraction

The crude-fibre residue was made into flour from the sweet-potato pulp. The material was collected from the separating container of the Breville juicer (residue remaining after starch separation step as described previously), spread onto an aluminium tray and oven dried at 40 ºC for 24 h. The material was then finely milled using the laboratory hammer mill, and sieved through a 300-micron sieve. Three batches of fibre flours were prepared. The fibres were assigned names, orange crude fiber (OCF), red crude fiber (RCF), and white crude fiber (WCF), packaged in polythene bags and stored at room temperature until further analysed.

2.5 Grinding and packaging of samples

Grinding was carried out with a laboratory scale hammer mill (Siemens-Schuckrt, Berlin, Germany), where the particles sizes were reduced

to 300-micron mesh fine flour. The grinding consisted of two steps, since it was not possible that all the chips were ground immediately, especially for the crude residue fibres and shredded flours. The sweet potato flour was then packaged and sealed under different names; starch, residue fibre and flour.

2.6 Moisture content

The moisture content of both raw material and isolated components of tubers were determined by the AACC method: 2g of sample were heated for 3 h at 100°C to constant weight (AOAC, 1995).

2.7 Protein content

The protein content was determined by Kjeldahl method (N x 6.25) according to the AOAC methods 4.2.5 (AOAC, 1995). The Kjeldahl method described was expedited by use of the Kjetec digestion and Kjeldahl distillation apparatus. To the dried sample were added two tablets of mercuric sulfate and 250 ml of H_2SO4. The mixture was heated at 450°C for 30 min in the Kjeltec digester until a clear solution was produced. Tube was placed in the Kjeldahl distillation apparatus and 10 of 0.5% w/v NaOH was add. The ammonia in the sample was steam-distilled for 5 min into a receiving flash containing 5% boric acid. The sample was titrated with 0.1% v/v HCL solution. The protein was calculated by the equation: % Nitrogen x 6.25.

2.8 Pasting behaviour

Rapid Visco Analyser (Model 4-D, Newport Scientific Pty Ltd, Warrewood, Australia) was used to analyse the pasting behaviour of the starch and flour suspension (4%) in a defined program as described in the general pasting method (RVA Application manual, version 5, 1997): Wheat flour (3.50 g) was substituted with SP starch, flour and fibre at 5%, 10%, and 15% (w/v). The dry material was placed in the aluminium canister for the RVA and 25 mls of water added. The mixture was then placed in the RVA apparatus with the plastic moulded paddle. Experimentation was conducted at a paddle speed of 160 rpm/min heated from 45°C to 90°C at 13 °C/min (setback) , held at 95°C for 2 min, cooled to 50 min at 13°C/min, and held at 50 for 2 min. Data extrapolated from the RVA curve was analysed by using a Thermocline for Windows version 22 (Newport Scientific Pty Ltd) to determine the peak Viscosity (maximum viscosity during heating and holding at 95°C), final viscosity (viscosity at the end of the test profile) and setback.

2.9 Preparation of biscuits

The biscuits were prepared according to the method described by Brennan and Samyue (2004), as illustrated in Figure 2.1. Biscuits were formulated using high-gluten baking flour (Champion flour, Goodman Fielder, NZ) according to recipe in Table 2.1. Doughs of the wheat-flour biscuit containing

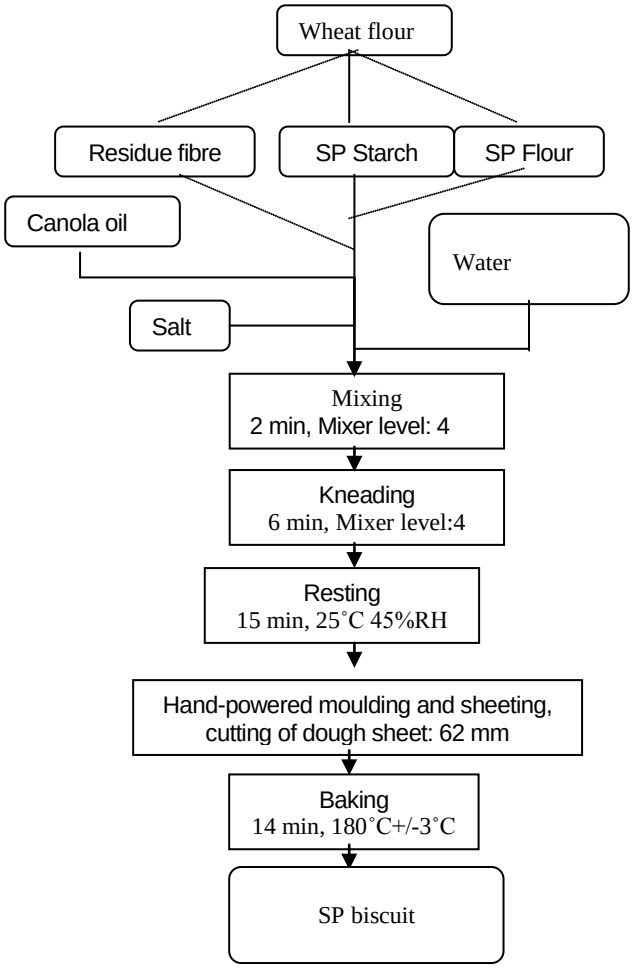


Figure 2.1: Modification of biscuit making method with Sweet potato (Brennan and Samyue, 2004)

starch, flour and fibre at different levels at 5%, 10% and 15%, respectively, were mixed and kneaded in a Kenwood mixer (Kenwood Chef- KM201, UK) for 1 min at speed 4. Water was then added and mixed further for 2 min (speed 4). After resting the dough (15 min at room temperature), the dough was sheeted to a thickness of 2 mm using a guide board, by manual rolling. Ingredients used for the control sample (100% wheat-flour) consisting of flour 225 g, canola oil 50 g, water 100 ml and baking powder 8 g. Biscuits were

shaped with a cutter of 62 mm diameter, and baked in a catering size conventional oven (Bistro AR 6 ES, Elextrolux, Sweden) on an aluminium tray at 180 ºC for 14 min. Biscuits were cooled for 30 min to room temperature (28.5 ºC), and analyzed for fracturability properties using the TA-XTplus texture analyzer (Stable Microsystems, Surrey, UK).

2.10 Evaluation of biscuits

Physical characteristics: The diameter (D) and thickness (T) of ten biscuits were measured using a micrometer. Four measurements were made at different sides for thickness of the biscuits and the average measurements (mm) were noted. Two measurements were made at two different sides for diameter and the average measurement was noted.

Fracturability characteristics: A Stable TA-XTplus Texture Analyser (Stable Microsystems, Surrey, UK) was used to analyse the fracture of the biscuits. The biscuits were placed on the bottom support ring. The probe moved downward at a speed of 1 mm/s until the samples were broken or maximum distance of 3 mm was travelled. Peak force (N) was recorded as the fracture force of the biscuit.

2.11 Total dietary fibre of biscuit

Total dietary fibre was determined using Megazyme starch assay kit (Megazyme AA/AMG) following the Approved AOAC method 945.37. 1 g sample was

weighed into a 250 ml beaker suspended in MES/TRI buffer solution and enzyme for TDF. 95% v/v ethanol was added to the mixture and allowed to precipitate at room temperature for 60 min, and then filtered through a crucible containing celite-using suction. Non-fibre material was removed from the suspension by extraction with 7% v/v ethanol and Acetone. The crucible containing fibre and ash was dried at 108°C+/ -5°C overnight and weighed. The fibre was removed by heating the crucible at 550°C for 3 hr and the weight of crucible and ash was obtained. The difference between the two weights equalled the amount of fibre present in the sample (Megazyme, International, Ireland, 2005).

2.12 Protein and Moisture Analysis of Biscuit

Chemical composition including moisture and protein (N 6.25), were determined in triplicate using AOAC methods 2.2.01and 4.2.05 respectively (AOAC, 1995). The moisture loss of the biscuit was measured as described by AOAC method. 2 g of each biscuit sample was dried to constant weight at 108°C+/ -5°C. The moisture loss of the bread was calculated from the loss in weight after drying and the loss weight converted to percentage by multiplying by 100 (AOAC,1995).

2.13 In vitro starch digestibility of biscuit

In vitro starch digestibility was carried out in duplicates on 25-mg sample of SP biscuit using a modified multi-enzymatic method of Brennan and Samyue (2004). Reducing sugar release (RSR) was calculated by 3, 5 – Dinitrosalicylic acid method (DNS) at 546 nm with the following main steps: The sample was weighed in a was 50 ml capped tube, instead of dialysis tube, and blended in

sodium phosphate buffer solution at pH 1.5 using 8M HCL and then filled with 5 ml of pepsin solution (115 U/ml). The pH was readjusted to 6.9 by adding 10% NaOH and made up to 49 ml with sodium phosphate buffer solution. The starch hydrolysed to glucose was catalysed by α-amylase solution (110U/ml buffer) in the tube, which was placed in a beaker containing 450 ml potassium phosphate buffer pH 6.9 at 37 ˚C for 3 hr.

The absorbance of sample blank (with deactivated enzyme) and absorbance of maltose blank (with deactivated enzyme plus unknown amount of maltose – 1 ml of 20% maltose solution) were run with each sample digestion, which allowed for the measurement of sugar release through the dialysis tube in the presence of food.

The method according to Gail Lorenz Miller (1959) outlined by Brennan and Samyue (2004), was adapted for the 3, 5 DNS method. 1 ml of the sample from the capped tube was mixed with 3 ml of DNS reagent (1% DNS ,0.2% phenol, 0.05% sodium sulphite, and 1% sodium hydroxide) and 1 ml of glucose (1ml/1000ml) , and heated at 90°C for 5 min to develop red brown colour. Prior to cooling, a 40% Rochelle salt was added to stabilise the red colour. The DNS method was repeated for every 30 min in duplicates and each time 1 ml sample was replaced by phosphate buffer solution

The absorbance was recorded at 546 nm and the reducing sugar release (RSR) was calculated in mg/g avail CHO as follows:

$$(A_{sample} \times 500 \times 0.95) / (A_{maltose} \times \text{carbohydrate in mg}) \times 100$$

A_{sample} represent the value of the absorbance at 546 nm of sample. $A_{maltose}$ represents the absorbance value of a solution containing 1 mg of pure maltose/ ml phosphate buffer. Carbohydrate represents the amount of (in milligrams) of

starch plus sugar contained in the sample, 500 ml is the total volume of solution and 0.95 is the conversion factor from maltose to starch.

2.14 Starch content of biscuit

The total starch analysis of SP biscuit sample was determined by amyloglucosidase/α-amylase, using Megazyme total starch procedure (Megazyme, AA/AMG) following the Approved AOAC method: AOAC Method 996.11 AACC Method 76-13 ICC Standard Method no. 168 RACI Standard Method. A sample (0.1g) was blended with 5 mL of 80% ethanol, followed hydrolysing of glucose by addition of thermostable α-amylase and amylglucosidase at 50C for 30 min in a glass test tube. The entire content was transferred to a 100ml volumetric flash and made up to 100ml with distilled water. About 30 ml of the solution was centrifuged at 3000 rpm for 10 min and 0.1 ml of diluted solution was added to 3 ml GOPOD reagent (Potassium phosphate buffer: ρ-hydroxibenzoic acid 0.22 M and sodium azide 0.4% w/w). The absorbance of each sample solution was then determined at 510nm and the method was calibrated by glucose standard solution and percent of glucose converted to percentage starch by multiplying by 0.90 (Megazyme, International, Ireland, 2005).

% Starch = ΔE x F / W x 90 (The factor 90 is used if we dilute the sample to 100 ml, and 22.5 if dilution is 25 ml)

ΔE = Abs read against reagent blank.

F = 100µg glucose / Abs for 100 µg glucose control

2.15 Bread preparation

Bread of sweet-potato starch, flour and residue fibre was formulated using a high gluten baking flour (Champion flour, Goodman Fielder, NZ) as detailed in Table 2.2

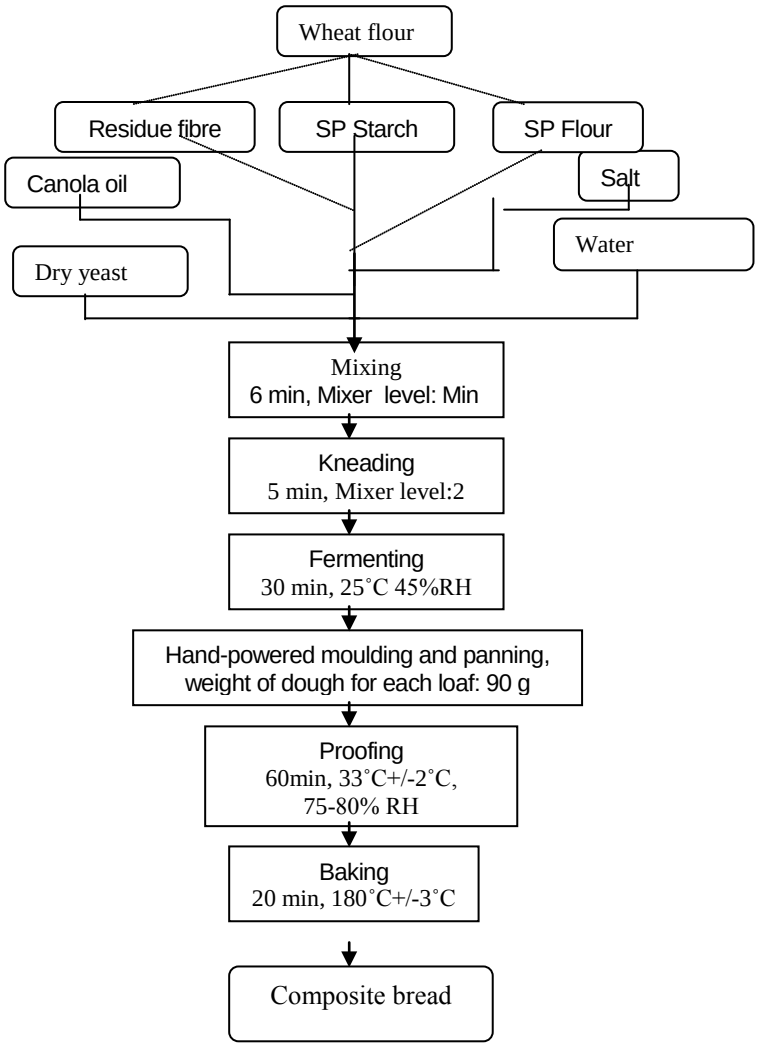


Figure 2.2: A modification of AACC optimised straight dough bread making method 10-10B (AACC, 10th edition, 1995)

For preparing different levels of starch (5%. 10% and 15%) with wheat flour at 95%. 90%, and 85% (w/w), the optimum straight dough bread making AACC

method 10-10B (AACC, 1995) was slightly modified as is illustrated in Figure 2. The mixture was mixed and kneaded with water in a Kenwood electrical mixer (Kenwood chef - KM201, Kenwood Ltd, Britain) and fermentation of dough was done in room temperature. The proofing of dough pieces was conducted in a proofer (unknown brand). Breads were baked in a catering size conventional oven (Bistro AR 6 ES, Elextrolux, Sweden). Ingredients used for the control sample prepared by AACC procedure were those of Tovar *et al* (1992) consisting of flour 300 g (100%), water 200 g (67%), salt 3 g (1%), yeast 3 g (1%) and canalo oil 1.5 g (0.5%), Sweet-potato starches, flours and fibres were incorporated into the recipe at 5%, 10% and 15% (w/w) replacement and additional levels for wheat flour, respectively.

2.16 Hardness of Bread

Bread sample was cut into 15-x 4-mm (width x thickness) piece and the measurement was recorded as the probe compressed the bread sample by 20% using a texture analyser (TA, model XT2, Stable Micro Systems, UK). The test speed was 50 mm/min and 5- kilo load cell was used and Peak forced (g) was recorded as hardness of the SP bread.

2.17 Loaf Volume (LVOL)

Volume of bread loaf was measured by rapeseed displacement using AACC method (1930). Bread sample was placed into the plastic container that was somewhat larger than the sample, and the plastic container was placed into a larger container (for catching stray seeds). The plastic container was filled with

rapeseed by pouring the seed from a large measuring cup through a funnel at as constant a rate as possible. The plastic container was slightly overfilled and excess seed were scraped into the larger pan with the edge of a spatula blade held vertically. The seed were then transfered (without spilling) with the aid of a funnel, into a large (1000-ml) graduated cylinder and the volume of the seed was obtain by difference and recorded.

2.18 Loaf weight of bread

The weight of bread sweet-potato after baking was assessed. The bread was measured using an analytical balance 30 min after baking.

2.19 Height of bread

The height (H) of bread was measured using a micrometer. Four measurements were taken on different sides for thickness of the bread and the average measurement (mm) was recorded.

2.20 Protein and Moisture analysis of bread

As already described in section 2.7 for protein; 2 g of each bread sample was used for the protein analysis.

The moisture of the bread was measured as described by AOAC method (1995). 2g of each bread sample were dried to constant weight at 108°C+/ -5°C. The moisture of each sample was calculated from the loss in weight after drying and

cooling the moisture dished in the desiccator. The difference between the two weights equalled the amount of moisture in the bread. The moisture weight converted to percentage moisture loss by multiplying by 100 (AOAC, 1995).

2.21 In vitro starch digestibility of bread

The starch content of sample was already described in section 2.15 from method of Megaezyme AA/AMG (*in vitro* digestibility of biscuit).

2.22 Statistical Analysis

Analysis of variance (ANOVA) was carried out using Minitab statistical package. Turkey's Multiple Range test was performed to determine and compare differences in starch, flour and fibre characteristics. Significance is considered when $p<0.05$ unless stated otherwise.

Table 2.1: Formula used for biscuit with sweet potato starch, flour and fibre

Sample	Level Replacement (%)	Wheat-flour (gm)	S/potato (gm)	Veg. oil (g)	Baking powder (g)	Water (mL)
Control	100	225	-	50	8	100
Orange SP starch	5	213.7	11.5	50	8	100
	10	202.5	22.3	50	8	100
	15	191.2	33.8	50	8	100
Orange SP Flour	5	213.7	11.5	50	8	100
	10	202.5	22.3	50	8	100
	15	191.2	33.8	50	8	100
Orange SP fibre	5	213.7	11.5	50	8	100
	10	202.5	22.3	50	8	100
	15	191.2	33.8	50	8	100
Red SP starch	5	213.7	11.5	50	8	100
	10	202.5	22.3	50	8	100
	15	191.2	33.8	50	8	
				50	8	
Red SP Flour	5	213.7	11.5			100
	10	202.5	22.3	50	8	100
	15	191.2	33.8	50	8	100
				50	8	
Red SP fibre	5	213.7	11.5	50	8	100
	10	202.5	22.3	50	8	100
	15	191.2	33.8	50	8	100
White SP starch	5	213.7	11.5			100
	10	202.5	22.3	50	8	100
	15	191.2	33.8	50	8	
				50	8	
White SP Flour	5	213.7	11.5	50	8	100
	10	202.5	22.3	50	8	100
	15	191.2	33.8	50	8	100
White SP fibre	5	213.7	11.5	50	8	100
	10	202.5	22.3	50	8	100
	15	191.2	33.8	50	8	100

Table 2.2: Formula used for baking wheat flour breads with starch, flour and fibre

Sample	Level Replacement (%)	Level Addition (%)	Wheat-flour (g)	S/Potato (g)	Water (mL)
Control	0	-	300	-	200
Orange starch	5	-	285	15	200
	10	-	270	30	200
	15	-	255	45	200
Orange starch	-	5	300	15	200
	-	10	300	30	200
	-	15	300	45	200
Orange flour	5	-	285	15	200
	10	-	270	30	200
	15	-	255	45	200
Orange flour	-	5	300	15	200
	-	10	300	30	200
	-	15	300	45	200
Orange fibre	5	-	285	15	200
	10	-	270	30	200
	15	-	255	45	200
Orange fibre	-	5	300	15	200
	-	10	300	30	200
	-	15	300	45	200
Red starch	5	-	285	15	200
	10	-	270	30	200
	15	-	255	45	200
Red starch	-	5	300	15	200
	-	10	300	30	200
	-	15	300	45	200
					200
Red Flour	5	-	285	15	200
	10	-	270	30	200
	15	-	255	45	200
Red flour	-	5	300	15	200
	-	10	300	30	200
	-	15	300	45	200
					200
Red fibre	5	-	285	15	200
	10	-	270	30	200
	15	-	255	45	200
Red fibre	-	5	300	15	200
	-	10	300	30	200
	-	15	300	45	200
					200
White starch	5	-	285	15	200
	10	-	270	30	200
	15	-	255	45	200
White starch	-	5	300	15	200
	-	10	300	30	200
	-	15	300	45	200
White flour	5	-	285	15	200
	10	-	270	30	200
	15	-	255	45	200
White flour	-	5		15	200
	-	10		30	200
	-	15		45	200
White fibre	5	-	285	15	200
	10	-	270	30	200
	15	-	255	45	200
White fibre	-	5	300	15	200
	-	10	300	30	200
	-	15	300	45	200

3.0 Pasting characteristic of sweet potato flour and isolate components (starch and residue)

Abstract

The starch, flour and fibre of red, orange and white varieties were studied, as part of this project to examine the pasting behaviour of sweet-potato starch (pure) and sweet-potato starch, flour and fibre combined with normal wheat flour, and evaluating possible differences at 5 - 15% levels. RVA Pasting behaviour examined indicated that pasting temperature obtained with red, orange and white starch by themselves were 64.35˚C, 64.45˚C and 66.15˚C, respectively; peak viscosity were 576.66, 560.56 and 658.00 RUV, respectively, and final viscosity amounted to 257.95, 224.54 and 282.11 RUV, respectively. RVA showed sweet-potato ingredients affected differently the pasting temperature, peak viscosity and final viscosity of the normal wheat flour ($p<0.05$). Orange starch exhibited high peak viscosity, while red exhibited low peak viscosity. Sweet-potato red, orange and white flour and fibre in combination with wheat flour decreased the peak viscosity and final viscosity, whereas the pasting temperature showed increase, as the levels of concentration increase. Fibre inclusion showed large reduction in viscosity and swelling of sweet potato starch. The setback values for flour and fibre, respectively, showed large decrease at high concentration, than the starch. Sharp pasting peaks were exhibited in pure starches when heated in water signify by enormous swelling of starch granules. Sweet potato starches of red, orange and white varieties exhibited the a-type swelling pattern, while flour of red, orange and white exhibited the b-type (moderate swelling) pattern.

3.1 Introduction

In the development of any food products from starchy crops, the knowledge of their physiochemical properties, in particularly those of the starch which is the major component, is needed to predict behaviour under given processing conditions. The properties of sweet-potato starches and flours, particularly their pasting properties, have been the subject of several investigations, some of which are related to the processing characteristics. These pasting properties can be related to the swelling and solubility properties of starch (Kartayama *et al*., 2002; Kohyama *et al*., 2002; Moorthy, 2002). A general illustration of chemical characteristics of starches obtained from various crops is shown in Table B.1 (Appendix B, page 164).

The starch of sweet-potatoes have been studied by a number of researchers (Rasper, 1969; Kohyama *et al*., 2002; Jangchud *et al*., 2003; Moorthy, 2002; Chen *et al*., 2003 and Noda *et al*., 1995). The starch of sweet potato is similar to other starch in being a polymer composed of anhydroglucose units of carbohydrate, with and is the major storage energy in various plants in nature. Starch of most sweet potato species is composed of a mixture of amylose and amylopectin. Sweet potato starch is reported to possess a-type (high swelling) pattern (Kartayama *et al*., 2002; Kohyama *et al*., 2002; Jangchud *et al*., 2003).

Like those from many other roots and tubers, sweet-potato starch granules are medium size with a smooth round oval shape (Noda *et al*., 1995; Moorthy, 2002). Sweet-potato starch is one of the least commonly used starches for

food; its granules range in size from 4 to 40 microns. Starch can be extracted by grinding the starchy crops, followed by wet separation techniques. The starch granules will sediment in the water due to their higher density. Use of sweet potato starch in foods depends on the viscosity of the starch paste.

Flour and fibre are another component of sweet potato and they differ significantly in the function and chemical properties to starch component (Wanda, 1987; Jangchud *et al*., 2003; Brennan, 2005). Pasting profile of the flour cannot be used to indicate the pasting properties of the starch, as most of the pasting parameters of the flour were not significantly correlated to the pasting parameters of the starch. Indeed sweet potato flours exhibited b-type (moderate swelling) pattern with much higher peak viscosity in composite type than starch blend with wheat flour. Gelatinisation temperature of sweet potato starch and flour may vary from 65-90˚C, whilst that of flour is higher than starch (Coursey and Ferber, 1979; Moorthy 2002; Jangchud *et al*.,2003). Absorption properties of sweet potato flour are relatively stable, with a water binding capacity between 62.4% to 70.4% and an absorption capacity of 5.02 g/g (Moorthy, 2002 and Jangchud *et al*., 2003). Crude fibre is derived from tuber extractions and may vary to greater extent on the techniques and sieves that are used for removal of the fibrous material. Crude fibre is defined as a non-starch polysaccharide and is a soluble fibre. It has a viscosity-altering behaviour where it affects the viscous properties of liquid and semi-liquid food products, and alters their textural properties (Brennan, 2005).

Thus, the pasting behaviour is very important for the starch and flour characteristics and their functionalities. Useful information such as pasting temperature, peak viscosity, and breakdown and setback value can be obtained from the profiles determined with Rapid Visco Analyser (RVA), apart from different analytical techniques such as differential scanning calorimetry (DSC), nuclear magnetic resonance (NMR) spectroscopy and Brabender viscoamylography (Hoover, R. 2001; Moorthy, 2002).

Understanding the viscosity or pasting behaviour of starch and flour were significant in this study, where the pasting properties were varied at known conditions to allow better understanding of the critical parameters affecting pasting gelatinization and better control during starch processing, which are very critical as fundamental knowledge for development of starch based products.

In this study, RVA is used to investigate the effect of three different sweet-potato fractions (5%, 10% and 15%) on starch, flour and fibre pasting properties as part of investigation on model-system interactions between fractions of three major varieties and wheat flour and their pasting properties.

3.2 Material and Methods

Three (3) commercial sweet potato varieties: white kumara, red kumara and orange kumara, were purchased from the supermarkets in Palmerston North. Samples were peeled and ground in juice extractor (Juice Foundation

Australia) at low speed, according to methods in chapter 2. Starch from the sweet potato was obtained by wet separation (starch slurry sediment through gravitational force), filtration (using 100-200 nylon screen) and then followed by hot air drying in the pilot plant unit at Massey University, based on the procedure 2.4 in chapter 2. Flour was milled after sweet-potato was chopped and dried, and while residue fibre was separated from the juice extractor, rinsed thoroughly with distilled water, dried and milled into fined powder, accordingly to methods in Chapter 2.

Pure kumara starches from the three varieties and wheat flour were at three different combinations: 5%, 10%, and 15%, were added to wheat flour of 95%, 90%, 85% combination.

Test samples were analysed on an RVA-4, using ICC Method No 162 and Standard 1 profile using diluted water along. Sample weighs were corrected on the basis of 4 g at 14% moisture for wholemeal flour and 3 g for starch.

The starch pasting curves were determined and expressed as Rapid Viscosity unit (RVU). Similar procedure was repeated for flour and fibre (refer to methods in chapter 2).

3.3 Results and Discussion

3.3.1 Composition of sweet-potato starch

Table 3.1 presents the chemical composition of the sweet-potato-wheat flour combination. The amount of protein and dietary fibre in wheat flour was higher than in composite flour.

Table 3.1 Chemical Compositions (% w/w raw material) of three varieties of sweet-potato

Components (%)	Sweet-potato Varieties*		
	Orange	**Red**	**White**
Amylose content	14.7±0.53a	13.3±2.15c	13.8±0.2c
Total starch(dmb)	71.7±0.67a	85.0±0.32c	83.8±0.47b
Total starch (as is)	14.3±8.34a	26.6±8.63c	22.7±0.12b
Protein (dmb)	2.1±1.87a	3.8±2.31b	3.8±1.95b
Moisture content	68.0±0.62a	73.0±0.12a	80.0±0.55b

* means of 3 different samples; letters represent significant differences at $p<0.05$.

3.3.2 Pasting behaviour

The pasting behaviour, i.e curves of apparent viscosity as a function of temperature, the initial temperature which the viscosity increase (pasting temperature), the temperature at which the peak viscosity for normal wheat starch containing different sweet-potato ingredients: OS, OF, OCF, RS, RF, RCF, WS, WF or WCF (at 5 to 15% concentration levels) are reported in Table 3.3 - 3. 5 and Fig.3.1

Pasting temperature of 3 sweet potato starches, pure orange starch (OS) , pure red starch (RS) and pure white starch (WS) were recorded as 64.35˚C, 64.45˚C and 66.15˚C , respectively (Table 3. 2), The literature has shown that the pasting temperature of sweet potato starch varied between 61.5 and 86.3°C (Rasper, 1969; Jangchud *et al*., 2003; Chen *et al*.,2003). Further studies by Noda *et al.* (1995); Kohyama *et al.* (2002); of new sweet potato varieties showed the range to be 67.2 – 73.8°C. However, pasting temperatures of 3 sweet-potato starches, OS, RS and WS starch were generally lower than the corresponding ranges of sweet potato starch reported by Rasper (1969) ; Noda *et al* (1995); Moorthy (2002); and Janghud *et al*., (2003). This effect on the pasting temperature of 3 sweet potato starches may be affected by changes in the interior structure of starch as has being discussed by Kohyama *et al*., 2002, Hsu *et al*., 2004). This result suggests that the change in starch structure of OS, RS and WS are caused both in the amorphous and the crystalline regions. Shi and Seib (1995) reported that the melting temperature of the crystallites in a granular starch is

greatly affected by the surrounding amorphous regions. Chen *et al* (2003) suggested the effect is probably due to size of starch granules; large granules are associated with lower pasting temperature and high swelling properties (Kohyama *et a*l., 2002). From this study, starch granules of WS were smaller in size than of OS and RS, thus may have contributed to a higher pasting temperature (66.6°C). However, pasting temperature did change with the increased in the starch concentration when added to wheat flour (Figure 3.1). Peak viscosities of OS, RS and WS were 576.66, 560.56 and 658.00 RVU, respectively; the final viscosities of OS, RS and WS amounted to 257.95, 224.54 and 282.11 RVU, respectively.

Different types of sweet-potato ingredients showed different affects on the pasting temperature, the peak viscosity and final viscosity of normal wheat starch ($p<0.05$). The addition of sweet-potato starch generally increased the pasting temperature (Figure 3.1 and Table 3.4). The value of the peak viscosity was generally similar to the control sample but at high levels (OS15% , RS15% and WS 15%). This effect is probably due to the amount of starch present in the mixture. Sugar molecules were reported to increase the starch gelatinisation temperature by reduction the level of solvents plasticization (Perry, 2002). Furthermore, Perry (2002) demonstrated that the mechanism of starch gelatinisation is not affected by the addition of starch-sugar molecules but that the kinetics of gelatinisation is simply translated further up the temperature axis. This could be clearly seen in this study, where the pasting of the normal wheat starch was translated to higher temperatures when sp starch was added.

In Figure 3.1, high peak viscosity was exhibited in all pure starches and they become thinner rapidly before thickening on cooling. This result conforms to the findings cited by Moorthy (2002). The OS starch had a greater retrogradation tendency than the RS and WS starch as indicated by the setback value of 565.42 for OS, 122.38 for WS and 266.04 for RS. The "setback" value is related to the amylose content and retrogradation of starch. However, comparing the 3 sweet potato varieties the amylose content of OS (14.7%), RS (13.3%) and WS (13.7%) starch were not greatly different. This is in good agreement with Osundahunsi et al. (2003) that red and white starch did not differ in their gelatinisation properties.

In contrast to starch, the addition of sweet potato flour to normal wheat starch, without sweet-potato starch, decreased the final viscosity considerably with increase flour concentration ($p<0.05$). The peak viscosity of normal wheat starch was decreased by addition of flours (Figure 3.2 and Table 3.5). However, the peak viscosity markedly decreased at high flour concentration and increased the pasting temperature (Table 3.5). Different effects of the addition of flour and addition of wheat flour were experienced, as the heating affects upon the formation of viscose mixture and gel (Figure 3.2)

In comparison with starch addition, the effect of fibre addition to wheat flour is more pronounced than the flour addition ($p<0.05$). This was evident in this study, where the pasting temperature of normal wheat starch was greatly decreased when crude fibre was added (Table 3.6). Fibre decreased the peak

viscosity of the normal wheat starch from 344.12 RVU to 47.97 RVU) for addition of fibre to normal wheat starch, and thus, this peak viscosity did changed greatly with an increased in the fibre concentration (Tab 3.6). However, final viscosity was low for fibre concentration (5%) and then decreased significantly at higher fibre concentrations ($P<0.05$). Opena *et al.* (1989) have reported that highly rich fibre (ß-glucans) caused a large reduction in viscosity and swelling of potato starch.

The setback values were decreased greatly when the concentration is high for, both flour and fibre additions (compared with starch). The values indicated that both fibre additions and flour addition had a very rigid viscose formation than starch additions. This conformed with results obtained by Moorthy, (2002) illustrating that the pasting examination of the starch-water paste showed rigid viscous behaviour and lower gel strength for most of the sweet-potato starches compared to other tropical root starch.

A comparison of pasting behaviour of starches and flours addition is shown in Figure 3.1 - 3.2. A sharp pasting peak signifies enormously swelling of the granules of starches when heated in water, and then the internal bonding forces became tenuous and fragile toward shear forces as shown by the rapid and major thinning during heating. According to the classification of Schoch and Maywald (1968), sweet potato starches (OS, RS and WS) exhibited the a-type (high swelling) pattern. The starch granules of addition flours (OF, RF and WF did not swell excessively and were less fragile to shear, thus exhibiting a lower pasting peak and much less thinning during cooking

compared to the starches additions (OS, RS and WS), hence the flours exhibited the b-type (moderate swelling) pattern.

Table 3.3: RVA pasting characteristics for different sweet-potato starches (pure) at varying levels of wheat flour

*Starch	Level **%	Pasting Tempt (°C)	Peak viscosity (RVU)	Setback (RVU)	Final viscosity (RVU)
Control	0	67.65±0.14e	344.74±0.54h	134.61±0.34i	334.8±0.58h
OS	100	64.35±0.03b	576.66±0.06a	565.42±0.40a	257.95±0.00a
RS	100	64.45±0.12b	560.56±0.01b	122.375±0.11c	224.51±0.00c
WS	100	66.15±0.0.55c	658±0.04c	266.04±0.17b	282.11±0.00b

*Means of 5 different samples

**Control= wheat starch, WS= White starch , OS= Orange starch, RS= Red starch

Table 3.4: RVA pasting characteristics for different sweet-potato starch at varying levels of wheat flour

*Starch	Level **%	Pasting Tempt (°C)	Peak viscosity (RVU)	Setback	Final viscosity (RVU)
Control	0	67.65±0.14 a	344.74±0.54bd	134.61±0.34 cf	334.8±0.58b
OS	5	67.00±0.00 ab	342.52±1.51a	134.56±0.73c	270.57±1.06a
	10	66.05±0.00c	341.16±0.54a	128.49±0.57b	329.26±0.21b
	15	67.91±0.91a	264.34±0.34b	104.91±0.00a	330.3±1.73b
RS	5	67.80±0.00a	348.46±0.29b	122.57±0.13e	176.91±1.12c
	10	69.87±0.62d	323.06±0.17b	120.86±0.97b	313.59±0.62d
	15	85.70±0.00c	148.55±0.45c	74.79±0.81d	332.54±1.01b
WS	5	69.30±1.06ad	364.69±0.12d	136.23±0.18f	345.21±0.08e
	10	69.35±0.07ad	362.91±0.53d	125.86±3.93be	346.85±5.99e
	15	70.25±0.07d	358.63±3.87d	123.58±0.11be	347.43±0.70e

*Means of 5 different samples.

**Control= wheat flour, WS=White starch;, OS=Orange starch; RS=Red starch

Table 3.5: RVA pasting characteristics for different sweet-potato flour at varying levels of wheat flour

*Starch	Level **%	Pasting Tempt (°C)	Peak viscosity (RVU)	Setback (RVU)	Final viscosity (RVU)
control	0	67.65± 0.14d	344.74±0.54e	134.61±0.34g	334.8±0.58 e
OF	5	68.98±0.60b	138.03 ± 37.9a	86.65±0.03a	131.72±55.9 a
	10	68.60±0.07b	68.27±0.42b	25.98±0.47b	41.29±0.65 b
	15	68.60±0.07b	48.14±0.35b	13.405±0.06c	22.08±0.12 b
RF	5	69.03±0.61b	238.1±0.21c	112.295±0.01d	250.55±0.32 c
	10	69.35±0.07bc	102.34±1.05d	56.98±0.76a	100.39±1.00a
	15	69.80±0.64bc	72.71±0.47bd	38.095±0.35e	65.28±0.18ab
WF	5	69.38±0.04bc	160.1±0.46a	86.375±0.90f	170±0.62d
	10	67.65±0.14c	116.65±0.88b	59.505±0.59c	107.86±1.00b
	15	70.42±0.30a	63.52±0.56ad	19.03±0.09a	31.26±0.16a

*Means of 5 different samples

**Control= wheat flour; WF= White flour; OF= Orange flour; RF= Red flour

Table 3.6: RVA pasting characteristics for different sweet-potato fibre at varying levels of wheat flour

*Starch	Level **%	Pasting Tempt (°C)	Peak viscosity (RVU)	Setback (RVU)	Final viscosity (RVU)
Control	0	67.65±0.14e	344.74±0.54h	134.61±0.34i	334.8±0.58h
OCF	5	70.25±0.00a	114±1.46c	56.15±1.00c	94.75±2.17c
	10	70.70±0.57a	71.21±0.00a	28.47±0.35a	45.24±0.70a
	15	71.88±0.11b	47.43±0.76b	16.27±0.35b	26.11±0.53b
RCF	5	68.53±0.04d	244.35±0.23f	112.63±0.35d	253.76±2.29f
	10	69.43±0.11c	186.74±1.64d	93.750.64e	196.71±0.23d
	15	69.35±0.00c	152.92±0.06e	81.22±0.18f	160.48±0.06e
WCF	5	69.45±0.00c	138.57±8.75e	55.34±1.00h	118.89±8.63g
	10	69.80±0.64ac	89.85±2.28g	37.27±0.59g	60.46±0.70a
	15	69.85±0.57ac	68.85±1.94a	21.75±0.12b	35.61±0.47b

*Means of 5 different samples.

**Control= wheat flour, White fibre =WCF, Orange fibre= OCF, Red fibre= RCF

Figure 3.1: RVA viscosity profiles of 3 sweet potato-starches compared with different sweet-potato ingredients.
OS = Orange starch; RS = Red starch; WS = White starch

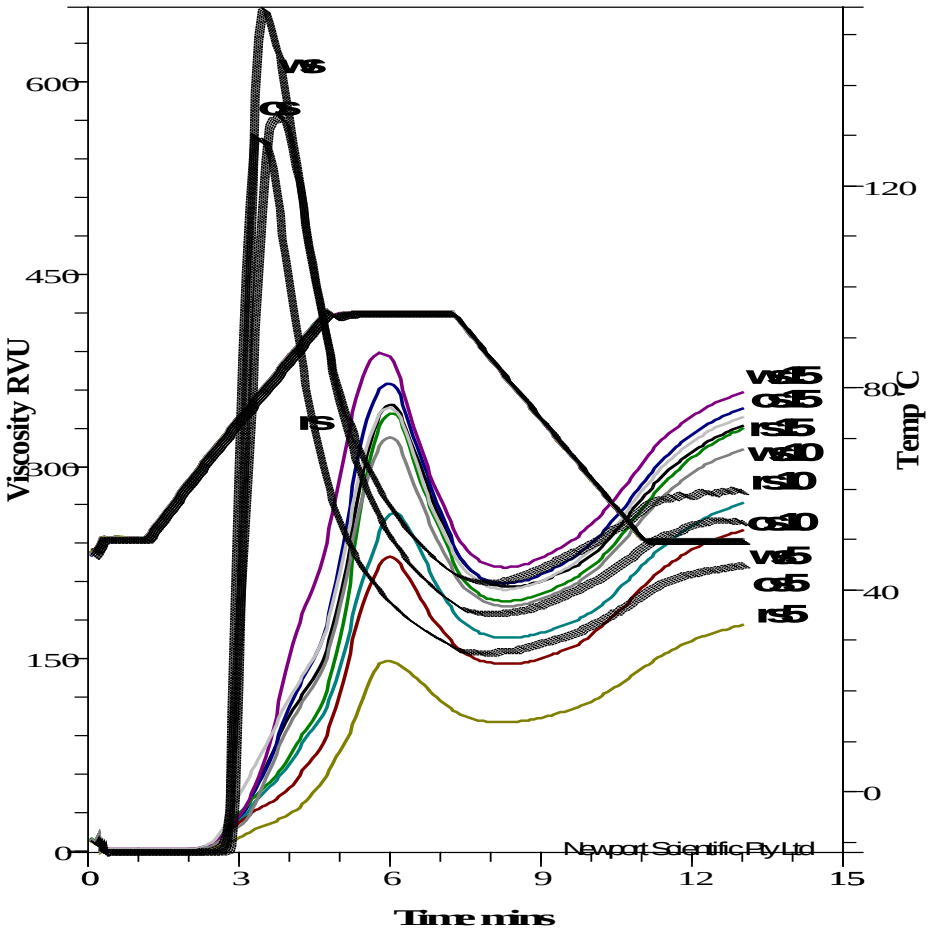
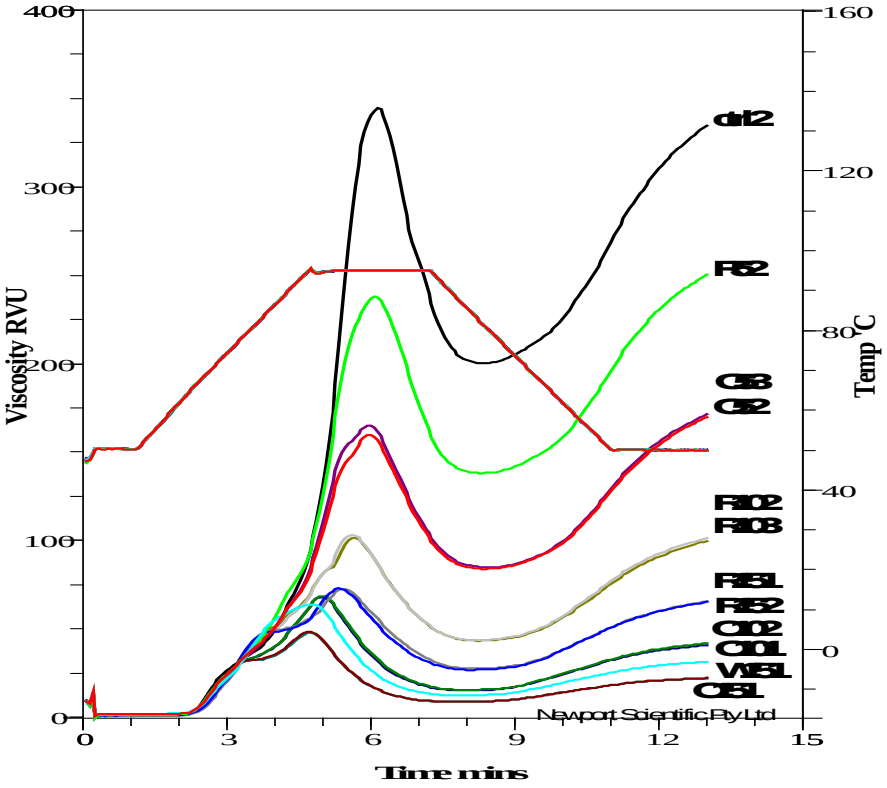


Figure 3.2: RVA viscosity profiles of wheat flour compared with different sweet-potato ingredients. Ctrl= Wheat flour; OF = Orange flour; RF = Red flour; WF = White flour



3.4 Conclusion

Different effects of sweet-potato starch, flour and fibre behaviour addition in wheat flour at 5-15% levels were examined. It is shown in the study that starch performed differently at different concentrations to their initial paste, forming a rigid paste, and compared to initial starch by themselves, which were weaker and too sticky.

RVA examination of the starch pastes indicated that the viscose paste obtained from white starch is significantly greater than that of other varieties. Orange starch exhibited high peak viscosity while red exhibited low peak viscosity. Pasting temperature of sweet-potato starches showed results ranging between 64.35°C and 66.15°C. The pasting temperatures were not significantly different within the levels of addition. Sweet-potato flour is shown to posses low peak viscosity profile.

The thickening potential of starch/wheat addition decreased with increased sweet-potato concentration. However, the thickening potential of starch-based product can be affected by other factors such as molecular structure, particle size, heat and shear condition.

Investigations between the three sweet-potatoes and wheat starch demonstrated that concentrations (level of addition) had influence on starch pasting properties, and can be based as a model system for interactions. The significance of these interactions is important, especially in food matrices

where desirable quality is anticipated and where dietary fibres are to be added as functional food ingredients.

3.5 Reference

Brennan, S .C, 2005. Dietary fibre, glycaemic response, and diabetes. *Molecular Nutrition Food Resource* **49**, 560 – 570

Chen, Z (2003). Physicochemical properties of sweet potato starch and their application in noodles, PhD Thesis, Wageningen University, The Netherlands.*http://library.wur.nl/wda/dissertations/dis3450.pdf*

Hsu, Chin-Lin., Hurang, Shu-Lin., Chen, Wenlung., Weng, Yih-Ming & Tseng, Chin-Yin (2004). Qualities and antioxidant properties of bread as affected by the incorporation of yam flour in the formulation. *International Journal of Food Science & Technology* **39** (2),pp 231-237

Coursey, D.G., Ferber, C.E.M., (1979). The processing of yams. Plucknett L.D (Editor). *Small-scale processing and storage of tropical root crops.* Westview Press, Colorado, pp 189-211

Hoover, R. (2001). Composition, molecular structure, and physicochemical properties of tuber and root starches: a review, *Carbohydrate Polymers* **45** (3): 253-267

Jangchud, K., Phiimolsiripol, Y., Haruthaithanasan, V. (2003). Physicochemical properties of sweet potato flour and starch as affected by blanching and processing, *Starch-Starke* **55**: 258-264

Kartayama, K., Tamiya, S., Ishiguro, K., (2002). Starch properties of new sweet potato lines having low pasting temperature, *Starch-Starke* **56** (12): 563-569

Kohyama, T Kato, S Tamiya, K Komaki - (2002*) New **Sweet Potato** Line having low Gelatinization Temperature and altered Starch Structure*, *Starch - Stärke,* 54 (2), pp 51-57

Leach H.W., McCowen, L.D., Schoch, T.J, 1959. Structure of starch granule 1. Swelling and solubility patterns of various starches. *Cereal Chemistry* **36**, 534-544

Jacobson, R. Mark; BeMiller, N James N. (1998)

Method for determining the rate and extent of accelerated starch retrogradation. *Cereal chemistry*, 75 (2): 22-29

Moorthy, S. N. (2002), Physicochemical and functional properties of tropical tuber starches: A review, *Starch-Starke* **54** (12): 559-592

Noda et Noda, Y. Takahata, T. Sato, H. Ikoma, H. Mochidas, (1995). Physicochemical properties of starches from purple and orange-fleshed sweet potato roots at two levels of fertilizer. *Starch/Stärke **48***, 395-399.

Opena, R.T., Takagi, H and Tsou, S.C.S (1987). AVRDC Sweet potato improvement program. *Paper presented in the International Sweet potato workshop*, ViSCA, Philippines , pp 20-25

Osundahunsi, O.F., Fagbemi, T.N., Kesselman, E., Shimoni, E. (2003). Comparison of the physicochemical properties and pasting characteristics of flour and starch from red and white sweet potato cultivars, *Journal Of Agricultural And Food Chemistry* **51** (8): 2232-2236

Perry, L (2002). Starch granule size and the domestication of manioc (Manihot esculenta) and sweet potato (Ipomoea batatas), *Economic Botany* ,**56** (4): 335-349

Rasper, V (1969). Investigations on starches from major starch crops grown in Ghana:. Particle size and particle size distribution Part II: *Journal of Science Food Agriculture* **20**, pg-642

Schoch T. J., Maywald E. C (1968). Preparation and properties of various legume starches. *Cereal Chemistry* **45**, 564-573.

Shi Y. C., Seib P. A (1995). Fine Structure of Maize Starches from Four *wax*-Containing Genotypes of the W64A Inbred Line in Relation to Gelatinization and Retrogradation. *Carbohydrate. Polymer* **26**, 141–147.

Staley, A.E, (1989). General Method for testing starch. *Applications manual for the Rapid Visco Analyse*r, New port Scientific, New South Wales, Australia, pp 20 –21

Starch in General', (1997). *Department of Food Technology and Nutritional Sciences, Food Science Group, Chair of Food Chemistry*, Wageningen Agricultural University, [Online] Available at http://www.ftns.wau.nl/agridata/starch1.htm

Wanda, Collins W. (1987), Genetic improvement for meeting human Nutrition needs. Quebedeaux, B and Bliss, F (Editors). *Proceedings of the first international symposium on horticulture and human nutrition, Contributor of fruits and vegetable*, Prentice Hall, pp 191- 199

Zhang, T., Oates, C.G. (1999). Relationship between alpha-amylase degradation and physico-chemical properties of sweet potato starches, *Food Chemistry* **65** (2): 157-163

4.0 Sweet-potato flour and isolate components (starch, flour and residue fibre) and their utilization in biscuit making

Abstract

Sweet-potato tubers of differing colours (orange, red and white) were used to produce tuber flour, a purified starch fraction and a crude fibre extract. Fractions from each tuber colour were added into a biscuit mixture as functional food and the effects of tuber source, and fraction composition were observed in relation to the physicochemical characteristics of biscuits. Addition of sweet-potato flour showed step-wise reduction in the peak and final viscosity values compared to the control flour. Addition of both orange and red sweet-potato starch to the wheat flour base generally reduced the peak viscosity of the pasted slurry, and the addition of white sweet-potato starch increased the peak viscosity values. Addition of crude fibre from sweet-potato tubers showed step-wise reduction of all the pasting slurry. Physical characteristics and texture analysis of biscuits were also studied and compared. The hardness of biscuits with orange flour was higher than those for red flour and white flour. The hardness of the flour-enriched biscuits decreased with increasing level of addition starch, flour or fibre. Addition of sweet-potato starch decreased the force required to fracture the biscuit compared to control. Fibre addition at lower levels (5-10%) significantly decreased the hardness of the biscuit and the biscuit thickness. Protein, starch and dietary fibre of sweet-potato fractions was found to affect all pasting properties.

Keywords: functional food, dietary fibre, starch, biscuits

4.1 Introduction

Sweet potato (*Ipomea batatas L. Lam*.), as it is mostly known, have been cultivated for domestic consumption in many countries in Asia-Pacific regions for many years. Despite the crop being indigenous and forming a part of the staple diet in the Asia-Pacific regions, the commercial potential of the sweet-potato tuber, and its isolated components such as starch, fibre, and flour, is yet to be maximised. Most sweet-potato tubers are commonly consumed fresh, baked, boiled, or steamed. The tubers have a relatively short harvest period of about 3-5 months (NARI, 2005) and work is required to extend the seasonality of the crop. This may be achieved by either altering plant physiology, improving tuber storage practices, or by investigating methods of utilizing the components of the tuber as food ingredients. To this end, a number of researchers have investigated the physicochemical and functional characteristics of a range of tropical tuber starches, highlighting their unique properties and potential field of applications (Hoover, 2001; Moorthy, 2002; Osundahunsi *et al*., 2003). The main utilisation of sweet potato is the starch manufacture and has many applications due to its starch composition. Within the food industry itself the list of sweet potato starch usages is quite large. Sweet-potato starch is used in many products including noodles, breads, cakes, biscuits, boiled sweets and confectionary products (Allemann *et al,* 2004).

The physico-chemical quality characteristic of sweet-potato products is of importance when considering its potential application into processed-food systems. The quality of sweet potato tubers, flours and starches appears not

only to be affected by the content of the starch in the tuber, but also the amylose-amylopectin ratio of the starch and the chemical composition of the tuber (e.g., fibre, lipids and proteins) (Tian *et al*., 1991). Variations in the quality of starch will alter the pasting properties of starch-moisture based processed foods, and subsequently impact on the rheological and textural characteristics of cereal products such as bread, doughs and biscuits (D'Egidio *et al*., 1982 & 1993). In particular, biscuit quality is highly influenced by the physiochemical properties of starch or flour (Tan *et al*., 2003) with the protein quality of flours important in maintaining biscuit shape and hardness. The variation in protein content in flour, and the way in which protein and starch components of the flour interact to form a dough matrix, largely explains variations in biscuit hardness (Gupta *et al*., 1993).

Sweet-potato tubers are regarded as being relatively high in starch and dietary fibre but low in protein. The low protein content and high dietary fibre content may present processing challenges to the food industry, although the use of dietary-fibre-rich products may be of nutritional benefit. For instance, previous research has indicated that the inclusion of dietary fibre into biscuit doughs may be useful in manipulating the rate of starch degradation during digestion, and may not necessarily affect the starch and protein matrix necessary for good biscuit quality (Brennan and Samyue, 2004).

The objective of this study was to investigate the possibility of using different fractions of commercially available sweet-potato tubers (flour made from sweet-potato tubers, isolated starch, and extracted fibre fractions) into biscuits, and

determines the effects on biscuit quality.

4.2 Materials and methods

4.2.1 Preparation of sweet-potato starch

Starches were extracted according to the method 2.2 in chapter 2, where the tubers were peeled, cut into 4-6 cm pieces, soaked in 0.2% sodium metabisulfite for 5 min, and the juice was extracted using a Breville juicer (Juice Foundation, Melbourne, Australia) at a low speed for 5 min. The resulting starch slurry was filtered through a screen (200-micron) and then passed again through a 100-micron screen. The filtrate was collected and allowed to stand undisturbed for 1h. The white starch fraction was collected, resuspended in distilled water, and allowed to settle; this process was repeated three times to eliminate sulphite residues. The collected starches were then dried in an oven at 40ºC overnight and packed in polyethylene bag.

4.2.2 Preparation of sweet-potato flour

Flours were prepared according to the methods 2.3 in chapter 2, where tubers were peeled, shredded into a 2-3 mm (thickness) and length up to 5 mm), soaked in 0.2% potassium metabisulfite for 5 min, pressed, spread evenly on a meshed wire tray and the dried in an oven at 40ºC overnight and packed in polyethylene bag.

4.2.3 Preparation of crude-fibre flour

The crude fibre residue was made into flour from the sweet-potato pulp according to method in section 2.4 in chapter 2, in which the material was collected from a separating container of Breville juicer (residue remaining after starch separation step as described previously), spread onto an aluminium tray and oven-dried at 40ºC overnight and packed in polyethylene bag.

4.2.4 Proximate analysis, total starch, dietary fibre and amylose content

As already described in section 2.12 for protein and moisture content described by AOAC methods 2.2.01 and 4.2.05 respectively (AOAC, 1995); 2 g of each biscuit sample was used for the protein analysis. Total starch content and total dietary fibre were determined using Megazyme starch assay kit (Megazyme Int., Wicklow, Ireland) following the Approved AOAC method 945.37. Measurements were made in triplicate for flour, starch and fibre samples.

4.2.5 Pasting properties

The method of analysing the pasting behaviour of different fraction of sweet-potato starch, flour , fibre using Rapid Visco Analyser (Model 4-D, Newport Scientific Pty Ltd, Warrewood, Australia) was described in section 2.8 in chapter 2 : Wheat flour (3.50 g) -paste water suspension was substituted with SP starch, flour and fibre wheat flour at 5%, 10%, and 15% (w/v) were sheared at a paddle speed of 160 rpm/min heated from 45°C to 90°C at 13 °C/min (setback) , held at 95°C for 2 min, cooled to 50 min at 13°C/min, and held at 50

for 2 min. Data extrapolated from the RVA curve was analysed by using a Thermocline for Windows version 22 (Newport Scientific Pty Ltd) to determine the peak Viscosity (maximum viscosity during heating and holding at 95°C), final viscosity (viscosity at the end of the test profile) and setback.

4.2.6 Preparation of biscuits

Biscuits containing sweet-potato starch, flour and residue fibre using high gluten wheat flour were made according to the method 2.9 in chapter 2. The biscuits were prepared according to the method described by Brennan and Samyue (2004) with slight modification (Table 2.1). The formulation was mixed and kneaded with water in a Kenwood electrical mixer (Kenwood chef - KM201, Kenwood Ltd, Britain) and dough was put to rest in room temperature. After resting, dough was manually sheeted into 2 mm on a guide board, and then cut and shaped using a cake cutter (62 mm diameter). Biscuit was baked in a catering size conventional oven (Bistro AR 6 ES, Elextrolux, Sweden).

4.2.7 Evaluation of biscuits

Diameter and thickness of biscuit measurement were described in method 2.10 in chapter 2, where the micrometer was used to measure the diameter (D) and thickness (T) of ten biscuits. Four measurements were made at different sides for thickness of the biscuits and the average measurements (mm) were noted. Two measurements were made at two different sides for diameter and the average measurement was noted.

Hardness of biscuit measurement was described in method 2.11 in chapter 2, where the Stable Micro System TA-XTplus Texture Analyser (Stable Microsystems, Surrey, UK) was used on the biscuits placed on the bottom support ring. The probe moved downward at the speed of 1 mm/s until the samples were broken or maximum distance of 3 mm was travelled. Peak forced (N) was recorded as hardness of the biscuit.

4.2.8 *In vitro* starch digestibility of biscuit

In vitro starch digestibility was carried out in duplicates on 25-mg sample of sweet-potato biscuit using a modified multi-enzymatic method of Brennan and Samyue (2004). Reducing sugar release (RSR) was calculated by 3, 5 – Dinitrosalicylic acid method (DNS) at 546 nm with the following steps described in Method 2.14 in chapter 2.

The sample was weighed in a was 50 ml capped tube, instead of dialysis tube which was placed in a beaker containing 450 ml potassium phosphate buffer pH 6.9 at 37 °C for 3 hr and absorbance were run every 30 min with each sample digestion, which allowed for the measurement of sugar release through the dialysis tube in the presence of food.

4.3 Statistical analysis

Analysis of variance (ANOVA) was carried out using Minitab statistical package. Turkey's Multiple Range test was performed to determine and compare

differences in starch, flour and fibre characteristics. Significance is considered when $p \leq 0.05$ unless stated otherwise.

4.4 Results and discussion

4.4.1 Starch analysis

The proximal analysis of sweet-potato starch, flour and crude fibre extracts from orange, red and white sweet-potato tubers is illustrated in Tables 1. The starch content of tuber flours varied greatly between tuber colours from 40% in white tubers to 64% in orange tubers and is in general agreement with the composition reported elsewhere (Jangchud *et al.,* 2002). Conversely, dietary fibre and protein contents were higher for the white tuber flour than that of red or orange tubers. This indicates the potential for variation in tuber composition based on the source of tubers analysed. A similar observation was made by Osundahunsi *et al*. (2003) who found that flour from Nigerian sweet-potatoes showed different chemical characteristics depending on the colour of the selected tuber (white having lower total carbohydrate content and higher protein and fibre content compared to red).

Starch contents of the extracted starch fraction are high (around 90% and more) indicating relatively pure starch fractions. The amylose content of sweet-potato starches ranged from 12.9% to 14.3%, similar to levels reported by Zhang and Oates (1999). Starch extracted from orange tubers showed higher amylose content than that of the starches extracted from white or red tubers.

Traces of fibre and protein were observed in the starches. The crude fibre extracts of the sweet-potato samples were fibre rich, with no starch detected in the fractions (Table 4.3).

4.4.2 Pasting properties

Table 1 reports the pasting characteristics of the different sweet-potato fractions and wheat flour combinations. Addition of sweet-potato flour significantly reduced the peak and final viscosity values compared to the control flour and this reduction was dose dependent. Flour from orange (OF) sweet-potato tubers affected the pasting properties greater than that of white (WF) or red (RF) sweet-potato flours. Addition of both orange (OS) and red (RS) sweet-potato starch to the wheat flour base generally reduced the peak viscosity of the pasted slurry, whereas the addition of white sweet-potato starch (WS) increased the peak viscosity values. The peak viscosity and final viscosity for OS were much lower than those of WS and RS ($p \leq 0.05$), excepting OS5 and WS5. Values for final viscosity showed a similar pattern with the addition of OS and RS reducing final viscosity in comparison to the control wheat flour sample. Setback values showed a significant decrease with the addition of sweet-potato starches compared to the control (excepting OS5 and WS5). The “setback” value is related to the amylose content and retrogradation of starch. The orange starch had a greater retrogradation tendency than the WS and RS starch as indicated by the setback value. This agreed with the value of amylose content in Table 4.2. The amylose content of OS (14.7%), WS (13.8%) and RS (13.3%) starch are not largely different. The higher amylose level of the starch from the

orange compared to white and red sweet-potato was consistent with its lower peak viscosity and probably resulted from the reduction of the swelling of starch by amylose compared to amylopectin. The peak viscosity of the flours was much lower than that of the starches because of swollen granules (Kartayama *et al*., 2004) and interaction with protein and fibre in the flour (protein on the surface granules) (Greene & Bovell-Benjamin, 2004).

The addition of crude fibre from sweet-potato tubers significantly decreased all pasting characteristics and this decrease was dose dependent. Orange (OCF) sweet-potato tubers showed a greater decrease in peak and final viscosity values compared to white (WCF) sweet-potato tubers and red (RCF) sweet-potato tuber samples. The decrease in viscosity of sweet-potato fibre in wheat-flour base is in agreement with the results of Brennan and Samyue (2004) who demonstrated a similar decrease due to presence of fibre in the flour mixes and the resulting interactions of swollen starch granules on the physico-chemical properties and the visco-properties of flour pastes.

4.4.3 Biscuit quality

Table 4.3 reports some of the physical characteristics and texture analysis of biscuits. Sweet-potato-flour-enriched biscuits generally showed similar textural and physical characteristics as that of the control wheat-flour biscuits. The hardness of biscuits with orange flour (OF) was higher than those for RF and WF. The hardness of the flour-enriched biscuits decreased with increasing level of addition in all samples. OF samples at 10%, RF 5% and WF 5 and 10%

showed similar fracture strength to that of the control samples. OF at 5% addition increased the force required to fracture the biscuit, whilst additions of flour at 15% reduced biscuit strength (Table 4.3).

The addition of sweet-potato starch decreased the force required to fracture the biscuit (compared to the wheat-flour control). As the level of sweet-potato-starch addition increased, so too did the force required to fracture the biscuit. The behaviour of sweet-potato-starch addition was similar for all tuber colours. The results are in good agreement with those reported by Greene e*t al*. (2004) and Osundahunsi *et al*. (2003) who reported that red and white starch did not differ in their gelatinization properties.

Fibre addition at lower levels (5-10%) significantly decreased the hardness of the biscuit and the biscuit thickness. The effect was dose dependent with increasing fibre addition further decreasing the force required to fracture the biscuits. Crude fibre extracts from red and white tubers behaved similarly, however crude fibre from orange (OCF) sweet-potato tubers showed a marked decrease in biscuit hardness at 10% and 15% levels. The reduction in biscuit hardness and also thickness of the biscuit is related to the dilution effect the fibre has on the starch-protein matrix of the biscuits. This is likely to disrupt the formation of a homogeneous matrix and, hence, lead to a weakening in biscuit structure. The greater decrease in OCF extract compared to both red and white the varieties is likely to be due to the elevated fibre contents within the OCF fraction.

4.4.4 Chemical properties of biscuits

The moisture content of the kumara samples varied from 4-8%. Orange sweet-potato flour had lower protein (3.7%) and starch (64.8%) content than white sweet-potato (4.38% protein and 39.9 % starch, Tab. 1). The starch content of sweet-potato starch varied from 98-84.7% due to the ratio of amylose-amylopectin content. White sweet-potato tuber has much less starch and is higher in total dietary fibre than the other two varieties. There was also an increase in protein and dietary fibre content for WCF. Latter increase was not observed in total starch and amylose content. The total starch content of OF and RF was higher than that of WF. Amylose contents of orange sweet-potato and white sweet-potato were 14.3% and 13.9%, respectively, which was supported by the report of Jangchud *et al*. (2003) in that the amylose content of orange flesh sweet-potato starch (~20%) was higher than that of purple flesh sweet-potato starch (~15%).

Upon baking of the biscuit a decrease was observed in starch content but dietary fibre content increased compared to the control. A large decrease in starch content of sweet-potato biscuits was due to a large amount of starch breakdown to maltose.

The dietary fibre content of biscuits increased after baking owing to the formation of some starch which was resistant to enzyme reaction (Bradbury, 1989).

4.4.5 *In vitro* digestibility studies

Digestion of starch samples was performed with α-amylase and the results are shown in Figure 1. Digestibility of sweet-potato starch, flour and fibre biscuits and wheat flour biscuit (control), represented as mg of glucose per 100 g of starch of hydrolysis at 60 min show wheat biscuit control was higher than those of sweet-potato biscuits. In vitro starch digestibility of biscuit samples containing wheat flour (control) was (0.33 mg/100g starch) which decreased significantly to (0.31,0.046, 0.056 mg/100g starch) at 15% level of OS, RS and WS substitution biscuit (Figure 4.1), whereas non-significant difference observed among the biscuits containing orange, red and white starch at 15% level of substitution.

Likewise in biscuit samples containing wheat flour (control - 0.33 mg/100g starch) a significant decrease of RSS (0.092, 0.126, 0.158 mg/100g starch) was observed at 15% level of OF, RF and WF substitution biscuit (Figure 4.2). Biscuit containing fibre yielded a low starch digestibility rate has shown to possess a relatively low susceptibility to α-amylase enzyme activity (Brennan and Samyue, 2004). Literature has shown that amylose rich in starch is difficult to swell or gelatinised, and it is digested slowly because of higher crystallinity in the structure due to extensive hydrogen bonding (Chen.2003; Juarez-Garcia, 2006). Other studies reported that retrogradation of amylose in starch generally suppress the reaction with amylolitic enzymes (Chen, 2003; Brennan, 2005) . However, it is believed that the amylose content is not the only factor influencing digestibility and that digestion is a complicated procedure affected

by many factors such as amylopectin structure, gelatinising temperature and phosphorus content besides, the amylose content. Fibre has a role in inhibiting the starch degradation. This relative resistance of fibre to digestive enzyme was found to be noticeable (Figure 4.3), and may be of importance to human health. However, further studies of this phenomenon are desirable, as their results could lead to some means of retarding these undesirable changes in dough formulation.

4.5 Conclusions

Different sweet-potato fractions and wheat flour combinations affected pasting properties and chemical composition (e.g., protein, starch and dietary-fibre content).

Starch of sweet-potato cultivars tested has low amylose content and high amylopectin content. The difference between the physiochemical properties was detected at three different concentrations. The addition of sweet-potato starches reduced viscosity of paste slurry. Hardness of sweet-potato biscuits for orange sweet potato was greater than red and white varieties. Fracture strength of biscuit increased at lowest level (5-10%) for starches and flours. Sweet-potato starches and flours could be used to substitute wheat flour at 5%, 10% without affecting the quality of the biscuit (combination of texture and biscuit size). Addition of sweet-potato fibre had negative effect on biscuit texture and size.

Biscuits containing sweet-potato starch and flour are low in amylose, and digest slowly because of lowly oriented and 'crystalline' areas within the granules enable to swell or to ungelatinised starch granules, whereas wheat control biscuit was able to gelatinised starch and exerted a greater effect upon digestibility. There are many other factors that need to be considered when analysing the in vitro starch digestibility such including amylose content, amylopectin structure and presence of fibre and gelatinising.

Table 4.1: Formulation of Biscuit

Sample	Control	Level of addition			Other ingredients
	100%	5%	10%	15%	
Baking Flour (g)	225	213.7	202.5	191.2	50g Vegetable fat
S/potato starch (g)	-	11.5	22.3	33.8	100mL Water
S/potato flour (g)	-	11.5	22.3	33.8	8g baking powder
S/potato fiber (g)	-	11.5	22.3	33.8	

Table 4.2: Chemical compositions of the extracted fractions from the three varieties of sweet-potato tubers

Sweet-potato	Moisture content %	Protein % (dmb)	Total starch % (dmb)	Total Dietary Fibre % (dmb)	Amylose %
Orange starch (OS)	6.28	3.73	98.0	0.6	14.3
Red Starch (RS)	4.81	3.65	88.1	0.7	12.9
White Starch (WS)	5.46	4.38	84.7	1.9	13.2
Orange flour(OF)	5.62	4.27	74.8	12.6	nd
Red flour(RF)	6.98	6.56	66.4	12.4	nd
White flour (WF)	4.39	8.79	66.9	13.6	nd
Orange Crude Fibre (OCF)	4.55	6.62	nd	70.3	nd
Red Crude Fibre (RCF)	5.37	7.85	nd	71.2	nd
White Crude Fibre (WCF)	3.92	11.64	nd	77.1	nd

nd: not determined, dmb: dry matter bases

Table 4.3: RVA results for different sweet-potato starch at varying levels of wheat flour.

Cultivar	Levels	Peak viscosity	Final Viscosity	Setback
STARCH	control	344.7 a	334.8 a	134.6 a
	OS 5	342.5 ac	330.3 b	134.6 a
	OS 10	264.3 b	270.6 c	104.9 b
	OS 15	341.2 c	329.3 b	128.5 c
	RS5	148.6 d	176.9 d	74.8 d
	RS10	348.5 e	332.5 b	125.6 e
	RS15	323.1 f	313.6 e	122.9 f
	WS5	364.7 g	136.2 f	136.2 a
	WS10	358.6 gh	347.4 h	123.6 f
	WS15	362.9 h	346.8 h	125.9 e
FLOUR	control	344.7 a	334.8 a	134.6 a
	OF 5	138.0 bf	131.7 bf	71.2 bf
	OF10	68.3 ce	41.3 ce	26.0 c
	OF15	48.1 c	22.1 c	13.4 c
	RF5	238.1 d	112.3 d	112.3 ad
	RF10	102.3 be	57.0 bef	57.0 be
	RF15	72.7 ce	38.1 bce	38.1 ce
	WF5	160.1 f	86.4 f	86.4 df
	WF10	116.7 b	107.9 bf	59.5 b
	WF15	63.5 ce	19.0 ce	19.0 d
FIBER	control	344.7 a	334.8 a	134.6 a
	OCF 5	114.0 b	94.7 b	56.1 b
	OCF 10	71.2 c	45.2 c	28.5 c
	OCF 15	47.4 d	26.1 d	16.3 d
	RCF5	244.3 e	253.8 e	112.6 e
	RCF10	186.7 f	196.7 f	93.7 f
	RCF15	152.9 g	160.5 g	81.2 g
	WCF5	138.6 h	118.9 h	5.5 h
	WCF10	89.8 i	60.5 i	37.3 i
	WCF15	68.9 a	35.6 cd	4.8 d

All comparison is among levels of flour, fibre or starch, respectively. Tukey 95% confidence interval. Each attribute means with different letters are significantly different ($p \leq 0.05$). OS= Orange starch, WS= White starch, RS= Red starch, OF=orange flour, WF=white flour, RF= Red flour, OCF= Orange crude fibre, WCF= White crude fibre, RCF= Red crude fibre.

Table 4.4: Fracture and Biscuit Measurement

Sample	Fracture (N)	Thickness (mm)	Diameter (mm)	Spread ratio
STARCH				
Wheat flour-CTRL	67.5±0 abc	6.0±0.0ab	43.7±0.0a	0.14±0.0a
OS5	42.4±6.8b	6.00±0.2a	43.5±0.3a	0.14±0.0ac
OS10	48.4±6.9c	6.51±0.5a	43.9±1.7a	0.15±0.0a
OS15	61.5±7.6c	6.21±0.3a	43.1±0.5ab	0.15±0.0bc
RS5	45.6±23ac	6.09±03a	43.8±0.2a	0.15±0.0c
RS10	48.8±6.8ac	6.28±0.4a	44.7±04ab	0.14±0.0bc
RS15	59.2±8.8ac	6.43±0.3a	44.7±0.3ab	0.14±0.0bc
WS5	43.5±0acd	6.63±0.3a	43.5±0.1a	0.16±0.0ab
WS10	54.4±0a	6.90±0.2a	44.0±0.3ab	0.17±0.0ab
WS15	55.2±0ac	7.05±0.2a	44.8±0.2ab	0.16±0.0b
FLOUR				
Wheat flour-CTRL	67.5±0 a	6.00±0.0ab	43.7±0.0a	0.14±0.0a
OF5	77.4±4.2b	6.01±0.0bc	43.5±0.3a	0.15±0.0ac
OF10	67.2±4.2bc	6.32±0.2a	44.8±0.7a	0.13±0.0a
OF15	61.6±8.8bc	6.53±0.8bc	43.4±1.3ab	0.15±0.0bc
RF5	64.1±6.2bd	6.02±0.4c	42.5±0.2a	0.16±0.0c
RF10	59.9±5.8bc	6.22±0.4bc	43.2±0.6ab	0.15±0.0bc
RF15	58.4±7.7b	6.55±0.4bc	44.3±0.3ab	0.15±0.0bc
WF5	69.4±6.2d	6.11±0.3ab	43.2±0.3b	0.14±0.0ab
WF10	60.5±7.7bd	6.34±0.3ab	43.2±0.4ab	0.15±0.0b
WF15	57.9±5.3ad	6.51±0.1ab	44.5±0.1ab	1.15±0.0ab
FIBRE				
Wheat flour-CTRL	67.5±0 a	6.00±0.0ab	43.7±0.0a	0.14±0.0a
OCF5	41.3±7.4a	4.9±0.2a	43.5±0.3a	0.14±0.0a
OCF10	29.0±3.1b	4.3±0.1a	43.4±0.3a	0.12±0.0a
OCF15	28.0±3.1bc	4.1±0.3a	43.7±0.2a	0.10±0.0a
RCF5	46.4±3.4bc	4.82±0.2a	43.5±0.3a	0.09±0.0a
RCF10	35.6±5.4b	4.50±0.2a	43.4±0.3a	0.12±0.0a
RCF15	31.2±4.0cb	4.21±0.1a	43.6±0.3a	0.09±0.0a
WCF5	49.8±8.4d	5.25±0.2a	43.5±0.3a	0.12±0.0a
WCF10	45.5±0.0bd	5.03±12a	35.4±16a	0.14±0.0a
WCF15	31.8±12ad	4.10±0.2a	35.3±16a	0.11±0.0a

All comparison is among levels of flour, fibre or starch, respectively. Tukey 95% confidence interval. Each attribute means with different letters are significantly different ($p \leq 0.05$). OS= Orange starch, WS= White starch, RS= Red starch, OF=orange flour, WF=white flour, RF= Red flour, OCF= Orange crude fibre, WCF= White crude fibre, RCF= Red crude fibre.

Table 4.5: Proximate Analysis of biscuits

Biscuits	Moisture content %	Protein % (dmb)	Total starch % (dmb)	Total Dietary Fibre % (dmb)
Wheat-Control	10.2	13.1	66.9	2.12
Orange starch (OS)				
5	9.4	8.8	56.4	4.91
10	11.4	8.5	59.3	9.67
15	9.8	7.0	61.7	8.4
Red Starch (RS)				
5	10.3	9.1	54.3	4.41
10	11.3	7.8	55.7	5.92
15	12.9	6.9	57.6	7.24
White Starch (WS)				
5	9.7	8.6	42.1	4.2
10	11.0	8.6	44.7	4.4
15	12.0	7.4	47.3	3.5
Orange flour(Of)				
5	11.6	12.8	48.3	5.5
10	9.7	10.4	50.7	5.5
15	10.9	8.7	55.4	5.7
Red flour(RF)				
5	11.3	10.1	51.4	5.80
10	10.9	9.6	53.5	5.80
15	9.8	10.6	55.8	8.73
White flour (WF)				
5	10.5	8.6	59.3	5.9
10	9.1	11.5	60.9	6.1
15	9.6	9.3	62.5	8.2
Orange Crude Fibre (OCF)				
5	11.0	10.3	45.5	23.8
10	12.6	9.6	37.8	23.7
15	10.2	9.4	39.8	28.7
Red Crude Fibre (RCF)				
5	10.6	9.0	49.5	21.5
10	11.8	10.7	50.4	23.7
15	9.5	7.8	48.4	31.2
White Crude Fibre (WCF)				
5	10.8	9.3	49.7	25.6
10	10.5	10.9	48.7	26.3
15	9.8	6.3	48.4	30.5

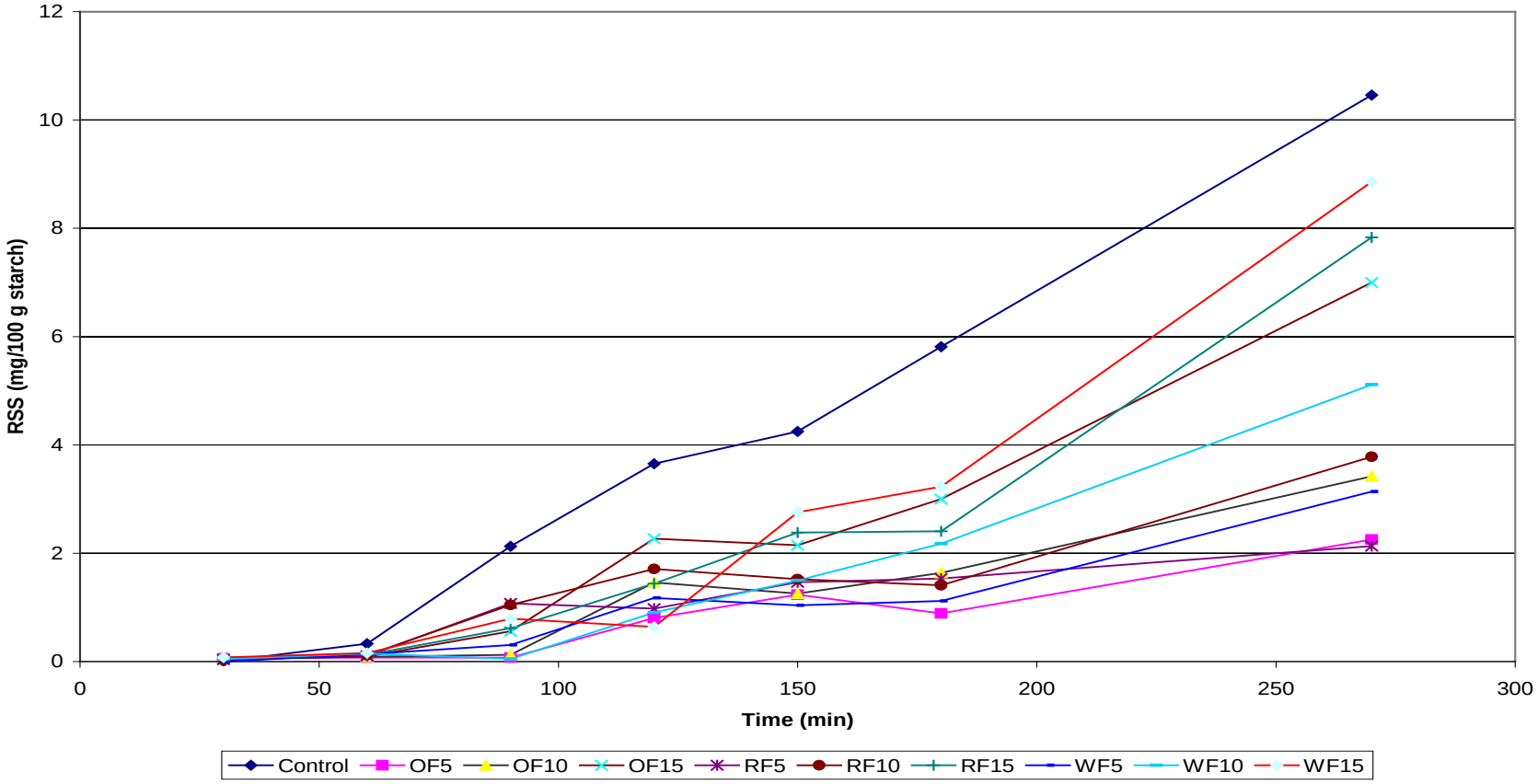


Figure 4.1: Sweet-potato starch biscuits and wheat control biscuit digestibility

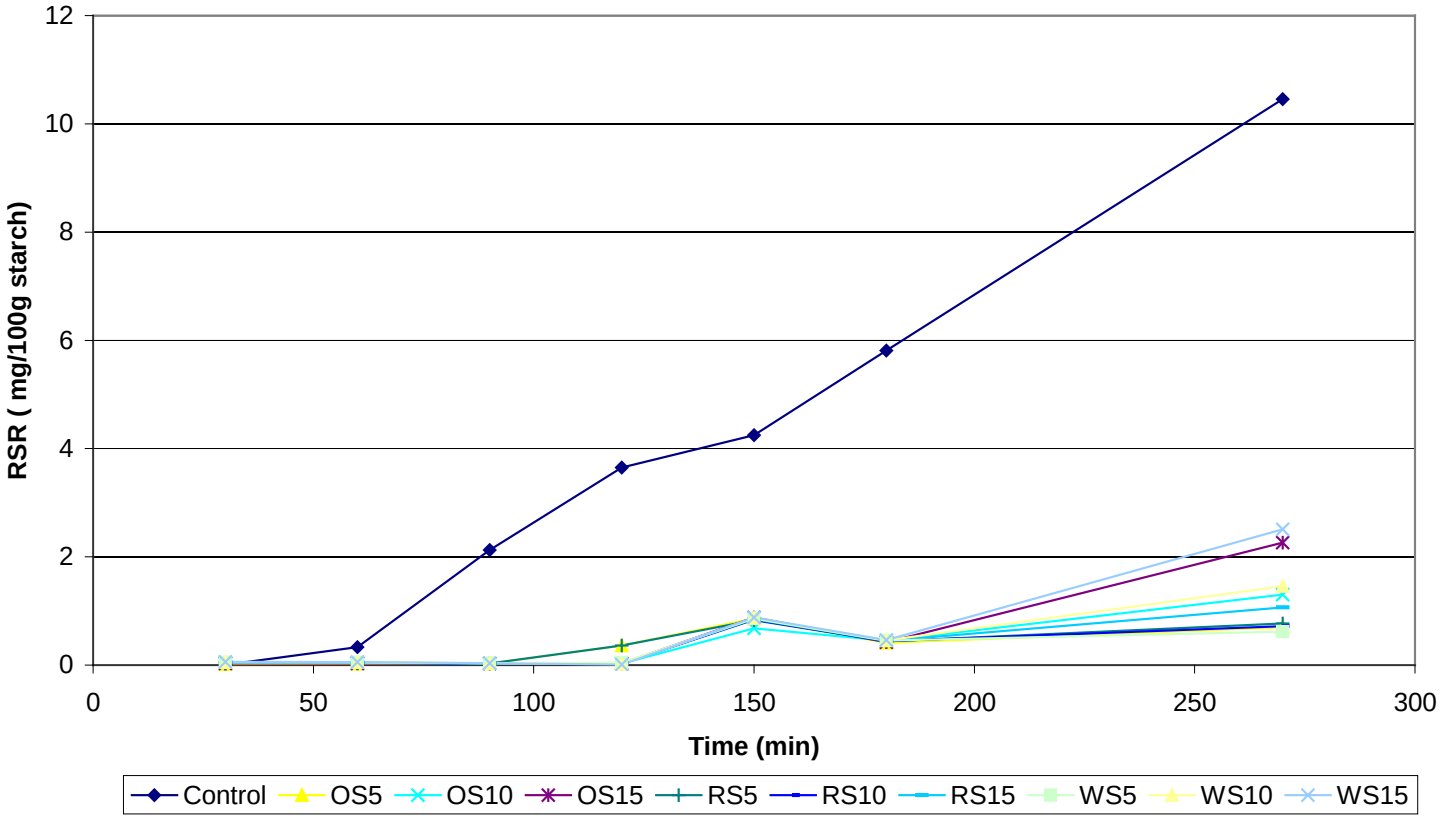


Figure 4.2: Sweet-potato flour biscuit and wheat control biscuit digestibility

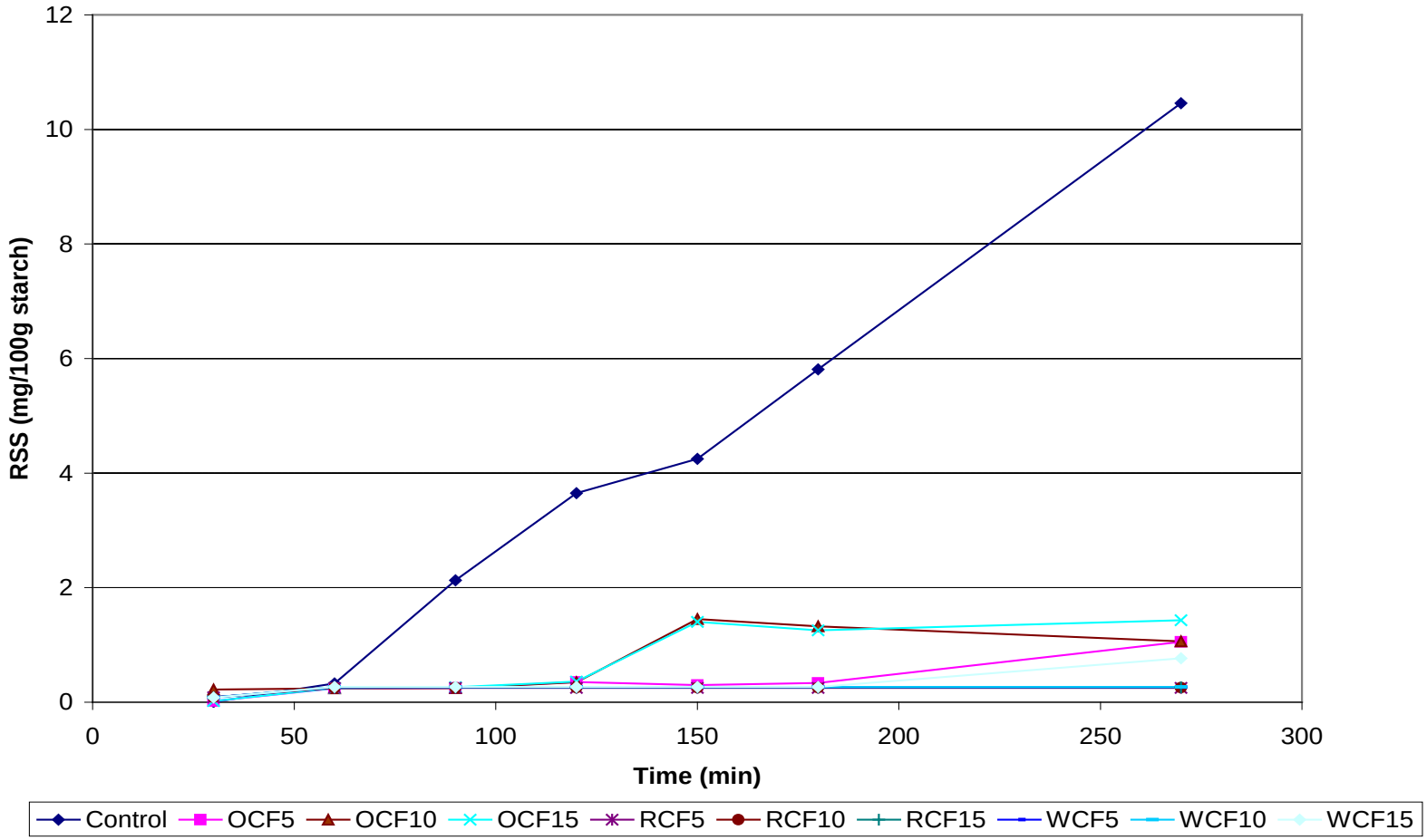


Figure 4.3: Sweet-potato fibre biscuits and wheat control biscuit digestibility

4.6 References

Allemann J, Laurie SM & Thiart S, (2004). Sustainable production of root and tuber crops (potato, sweet potato, indigenous potato, cassava) in southern Africa . *South African journal of botany* ***70*** (1): 60-66

AOAC International. (1995). *Official Methods of Analysis of AOAC International.* 16th Edition. Patricia Cunniff, (ed). AOAC International, Arlington, Virginia.

Bradbury, J. H. (1989). Chemical composition of cooked and uncooked sweet potato and its significance for human nutrition; Chapter 2 in "*Sweet Potato Research and Development For Small Formers"*,. Mackay, K.T (editor), The International Development Research centre, Canada, pp 234-237

Brennan, C.S & Samyue, E. (2004). Evaluation of starch degradation and textural characteristics of Dietary fibre-enriched biscuits. *International Journal of Food Properties*, **7**(3): 647-757

Brennan, S .Charles, 2005. Dietary fibre, glycaemic response, and diabetes. Molecular Nutrition*. Food Resource* **49**, 560 – 570

Chen, Z (2003). Physicochemical properties of sweet potato starch and their application in noodles, PhD Thesis, Wageningen University, The Netherlands *http://library.wur.nl/wda/dissertations/dis3450.pdf*

D'Egidio, M. G., De Stefanis, E., Fortini, S., Galterio, G., Nardi, S., Sgrulletta, D & Bozzini, A. (1982). Standardisation of cooking quality analysis in macaroni and pasta products. *Cereal Foods World* **27** 367-368.

D'Egidio, M. G., Mariani, B. M & Novaro, P. (1993). Viscoelastograph measures and total organic matter test: suitability in evaluating textural characteristics of cooked pasta. *Cereal Chemistry* **70** 67-72.

Greene, J.L. & Bovell-Benjamin, A.C. (2004). Macroscopic and sensory evaluation of bread supplemented with sweet potato flour, *Journal of Food Science* **69** (4) 167-173.

Gupta, R. B., Khan, K & MacRitchie, F. (1993). Biochemical basis of flour properties in bread wheat. I. Effects of variation in quantity and size distribution of polymeric protein. *Journal of Cereal Science* **17** 23-41.

Hoover, R. (2001). Composition, molecular structure, and physicochemical properties of tuber and root starches: a review *Carbohydrate Polymers* **45** (3) 253-267

Jangchud, K., Phiimolsiripol, Y & Haruthaithanasan, V. (2003). Physicochemical properties of sweet potato flour and starch as affected by blanching and processing *Starch-Starke* **55** 258-264

Juarez-Garcia,e. , Agama-Acevedo, e. , Sáyago-Ayerdi, S.G. , Rodríguez-Ambriz, S.L. and Bello-Pérez, L.A. (2006). Composition, digestibility and application in breadmaking of banana flour*. Plant Foods for Human Nutrition* **61**: 131-137

Kartayama, K., Tamiya, S & shiguro, K. (2004). Starch properties of new sweet potato lines having low pasting temperature *Starch-Starke* **56** (12) 563-569

Katayama, K., Komaki, K. & Tamiya, S (1999). Varietal and annual variations in pasting properties of sweet potato starch , *Breeding Science* **49** (3): 173-178

Megazyme Int., Wicklow, Ireland, 2004, www.megazyme.com

Moorthy, S. N. (2002). Physicochemical and functional properties of tropical tuber starches: A review *Starch-Starke* **54** (12): 559-592

National Agriculture Research Institute, (2005). Lowland sweet potato varieties, *The National of PNG*,: The Word Publisher, Papua New Guinea *http://www.thenational.com.pg/. March, p-12*

Osundahunsi, O.F., Fagbemi, T.N & Kesselman, E (2003). Comparison of the physicochemical properties and pasting characteristics of flour and starch from red and white sweet potato cultivars *Journal of Agricultural And Food Chemistry* 51 (8): 2232-2236

Oluwatooyin, F., Osundahunsi, O.F., Fagbemi, T.N., Kesselman, E & Shimoni, E. (2003) Comparison of the physicochemical properties and pasting characteristics of flour and starch from red and whit sweet potato cultivars. *Journal of Agiculturer, Food Chemistry.* **51** 2232-2236.

Wheatley, C.C. & Bofu, S. (2000). *Sweetpotato starch in China: status and future prospects*. Peru. International Potato Center (CIP), 4pp

Zhang, T & Oates, C.G. (1999) Relationship between α-amylase degradation and physico-chemical properties of sweet potato starches. *Food Chemistry* **65**, 157-163.

5.0 Utilisation of sweet-potato flour and isolate components in dough and bread systems.

5.1 Proximate analysis

Figure 5.1 - 5.10 and Table 5.1 - 5.3 illustrate proximate compositions (moisture and protein content) of the bread samples containing sweet-potato starch, flour and residue fibre at different composition level.

Moisture contents ranged from 8.69% to 24.38% (Table 5.1- 5.3) for the bread samples containing starch, flour and fibre at 5% - 15% levels. Control bread sample had an average moisture control of 16.48% , while having the protein contents of 8.95%.

Moisture content of bread containing red, orange and white (replacement and addition), sweet potato starch showed a step-wise decrease, as levels of concentration increase. Protein content also showed a similar decrease. Table 5.1 shows a significant increase in moisture content of red, orange and white starch at 5% level, but at higher level the moisture content decreased. The values of protein content in breads containing starch samples were below the control bread protein content.

Bread samples containing red, orange and white (replacement and addition) flours showed decrease in moisture and protein content, as the concentration levels increase. There was a greater increase in moisture observed at 5% in

orange and white flour reduction bread, as well as in addition mode. Protein levels for control bread were reduced from 8.96% to a much lower value when red, white and orange flour were used as the concentration levels were increased at replacement and addition mode.

Breads of red, orange and white residue samples recorded the lowest value of both protein (8.04%) and moisture (8.88%) compared with the other test breads, although the differences in amounts were not significant.

Statistical analysis revealed that there were no significant differences in proximate compositions of among red, orange and white starch and flour blends at different levels, except for fibre bread. Control bread made for comparative purpose was significantly different from all other breads containing sweet-potato ingredients.

Figure 5.1- 5.10 and Table 5.1 - 5.3 illustrate some physical characteristics such as loaf volume, loaf weight, hardness and specific loaf volume of breads comparing different sweet-potato ingredients: red, orange and white for starch, flour, and residue fibre (at 5 to 15% levels).

5.2 Physical characteristics

5.2.1 Loaf volume (LVOL)

Bread samples containing red, white and orange replacement and addition starch had LVOL ranging between 143.30 mL and 226.30 mL (Table 5.1).

Highest values were observed at 5% levels and lowest were observed at 15% levels. Both starch replacement and addition modes, showed inconsistency in LVOL (Table 5.1). In all case, replacement and addition starch showed reduction in volume of bread at high concentration level (Figure 5.1 and Table 5.1, respectively).

Bread samples containing red, white and orange flour, in both replacement and addition, had LVOL ranging between 151.80 mL and 215.00 mL (Table 5.2) The LVOL of control bread made from 100% wheat flour without sweet-potato was 176 mL. In general, the flour replacement mode greatly yielded higher LVOL than the addition mode (Table 5.2).

In all cases, both flour replacement and addition recorded a reduction in loaf volume, as concentration level increases, and the values were significantly different between the samples. Their values were higher at 5% level (compared to control bread) and decreased at high concentration level.

Bread samples containing white starch and white flour at 5% and 10 % for straight replacement, showed much higher loaf volume than the other breads ($p<0.05$).

Bread containing sweet-potato fibre had a marked decreased in height and volume values at high concentration levels (15%). The largest reduction in loaf volume was observed in sweet potato fibre (123.00 mL) at high replacement level.

The wheat bread control had the highest value for loaf height (60.0 g) compared to all the other sweet potato ingredients, (except red flour additions (5% and 10%) and white flour replacements (5% and 10%) and white starch at 5 and 10% replacement, which exhibited higher height values).

Among the bread samples, positive correlation existed between bread height and volume at the 5% significance level, in flour of both replacement and addition (Table 5.4). Starch breads show mixture of positive and negative correlation existed. Bread samples containing fibre recorded strong correlation between height and volume, at the 5% significance level (Table 5.4).

5.2.2 Loaf weight

Bread samples containing red, white and orange starch, in both replacement and addition, had loaf weight ranging between 75.15 g to 83.07 g (Table 5.1). Loaf weight of control bread was 75.0g and this weight differs significantly with increased in sweet-potato starch at 5 -15% levels. Bread containing sweet-potato starch at 15% level (in Figure 5.5), showed significant ($p<0.05$) changes in loaf weight, compared to control bread. At high concentration level, bread samples containing red, orange and white starch bread with addition mode exhibited maximum loaf weight ranging from 80.68.36 g to 80.75 g (Table 5.1).

Bread samples containing red, white and orange flour, in both replacement and addition, had loaf weight ranging between 75.15 g to 79.36 g (Table 5.2).

The loaf weight for control bread was increased from 75.g and up wards as flour concentration increases. In all case, both replacement and addition modes showed gradual increase in values of loaf weight as concentration levels increase.

For bread containing fibre, red, orange and orange replacement and addition had a marked decreased in loaf weight value at high concentration levels (15%). Biggest increased in loaf weight was observed in white addition fibre (83.07 g) at high concentration level.

In general, starch addition mode exceeded the replacement mode at 15% level, while in flour replacement exceeded addition mode. Furthermore, the significant difference ($p<0.05$) changes in loaf weight showed in starch bread than flour and fibre breads (Figure 5.13 & 5.15) (compare with control bread).

5.2.3 Specific loaf volume

Specific loaf volume was obtained by dividing the loaf volume by loaf weight. Specific loaf volume of breads decreased consistently and significantly with increasing levels of starch, flour and fibre, respectively.

In Table 5.1, specific loaf volume did not change for breads containing red and white replacement starch at 15% concentration levels, compared to control bread. Specific loaf volume for control bread at 2.33 mg/g was changed to 2.18 g (orange replacement), and rest of addition (1.83, 2.01 and

2.03 mg/g) at higher starch level (Table 5.1). 5% concentration level gave rise to specific loaf volume far above the control value, however as the concentration reached 15% level the specific loaf volume observed to be decreased (Figure 5.16 and Table 5.1).

Bread samples containing red, white and orange flour, in both replacement and addition, gave rise in specific loaf volume at 5% (Table 5.2). Specific loaf volumes for breads containing red and white addition flour at 10% concentration levels were similar to control bread ($p<0.5$), but significantly different with rest of the other flour bread samples.

In fibre samples, bread containing red, orange and white replacement and addition showed significant differences at higher concentration level, compared with control bread.

Among the bread samples, positive correlations existed between bread volume and specific loaf volume at the 5% significance level, except red addition starch that shows negative correlation. There was a strong negative correlation existed between bread weight and specific loaf volume ($p<0.5$).

5.2.4 Loaf hardness (Texture)

Bread hardness measured by TXT-2 (Stable Microsystems, Surrey, UK) revealed a step-wise increase in hardness value with increased in starch, flour and fibre levels (Table 5.1 – 5.3).

Bread samples with white replacement starch recorded lowest hardness values (1460 g) at 15%, followed by white addition starch (1504.17 g). In comparison with control bread, orange replacement starch gave hardness value ranging similar to control bread.

In flour samples, bread containing white replacement flour recorded the lowest value of hardness at 15% was 970.98 g and maximum hardness at 15% observed was 2152.75 g (orange addition), in Table 5.2. The hardness values for flour bread samples at 5% concentration level were generally lower the control sample. As the concentration increased the hardness values also increased.

In Figure 5.18 and Table 5.3, residue fibre breads showed the highest hardness values in both replacement and addition compared with the other test breads and were inconsistent. Unlike flour and starch, the differences in values were not significant.

Among the bread samples, there was a negative correlation existed between bread specific loaf volume and hardness at the 5% significance level.

5.3 Bread *in vitro* digestibility

Figure 5.1A – 5.6A and 5.1B - 5.3B illustrate the rate of digestion of bread samples with red, orange and white sweet potatoes in addition and replacement mode, respectively, with control (wheat) bread sample. Rate of

starch digestibility for bread samples are displayed as mg of carbohydrate per 100g of starch. Control bread was used as reference to compare the effect of sweet potato starch, flour and fibre ingredients on digestibility of starch.

The replacement and addition of different starch, flour and fibre at 5% -15% levels (Figure 5.2A, 5.4A, 5.6A, 5.1 - 5.3B) affected differently the rate and extent of reducing sugar release (RSR) at every 30 min intervals for almost 3 hr.

Figure 5.1A - 5.6A show curves of red, orange and white replacement and addition breads of starch digestibility, while Figure 5.1B - 5.3B show plots of red, orange and white starch digestibility for addition mode alone.

Figure 5.1A did not show satisfactory results, as the plots of starch hydrolysis for test breads containing starch addition ingredients at 5-15% addition did not compare well with previous research. In all cases, the addition mode exceeded the replacement mode of red, orange and white starch.

In comparison, plots of starch digestibility for starch addition bread observed in Figure 5.1A, were low compared to Figure 5. 1B. Plots of flour addition in Figure 5.3A were relatively low compared to flour addition in Figure 5.2B. Likewise, fibre addition in Figure 5.5A compared with plots in Figure 5.3B were comparatively lower than expected. As a result, Figure 5.1A, 5.3A and 5.5A were therefore deemed unsatisfactory, although there were noticeable effects of starch depletion recorded.

Figure 5.1B – 5.3B are repeated measurements of starch hydrolysis conducted to re-check the plots. These results appeared more consistent with

the previous results. The influence of red, orange and white starch in addition mode on the extent of starch hydrolysis was evident and a high extent of starch reduction (5 - 6 mg/g) was also observed in these figures.

Digestibility of breads containing sweet-potato starch at 5, 10 and 15% (addition levels) were higher than control-bread (except at 270 min, where starch figures slowly declined towards the control).

Figure 5.2A showed bread samples with of red, orange and white starch with a straight replacement mode. Starch digestion reduced, as concentration level increased. Similarly with red, orange and white flour with replacement mode, there was further decreased observed as concentration levels increase. The bread containing residue fibre at 5, 10, and 15% with replacement mode was showed significant reduction on digestibility. Fibre containing breads recorded the least RSR response (in both replacement and addition) compared with the other test breads.

Bread samples with sweet-potato components used in an addition mode showed significant increased in rate of *in vitro* starch digestibility compared to replacement mode. However, it was observed samples with presence of fibre differ significantly from starch and flour (Figure 5.1B - 5.3B). Sweet potato bread samples with the straight replacement mode showed reduction in *in vitro* starch digestion rate.

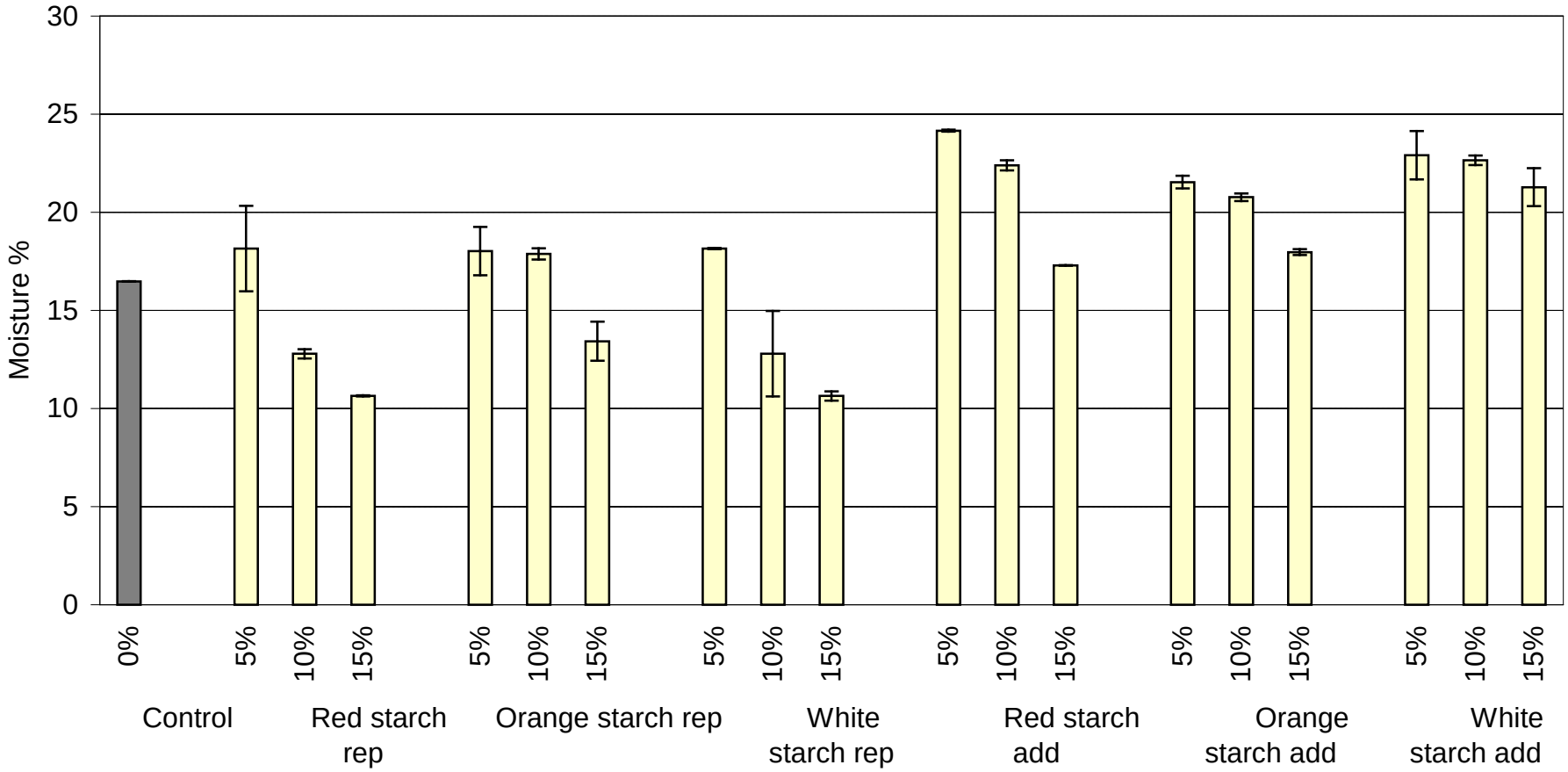


Figure 5.1: Sweet-potato starch effect on moisture content of bread

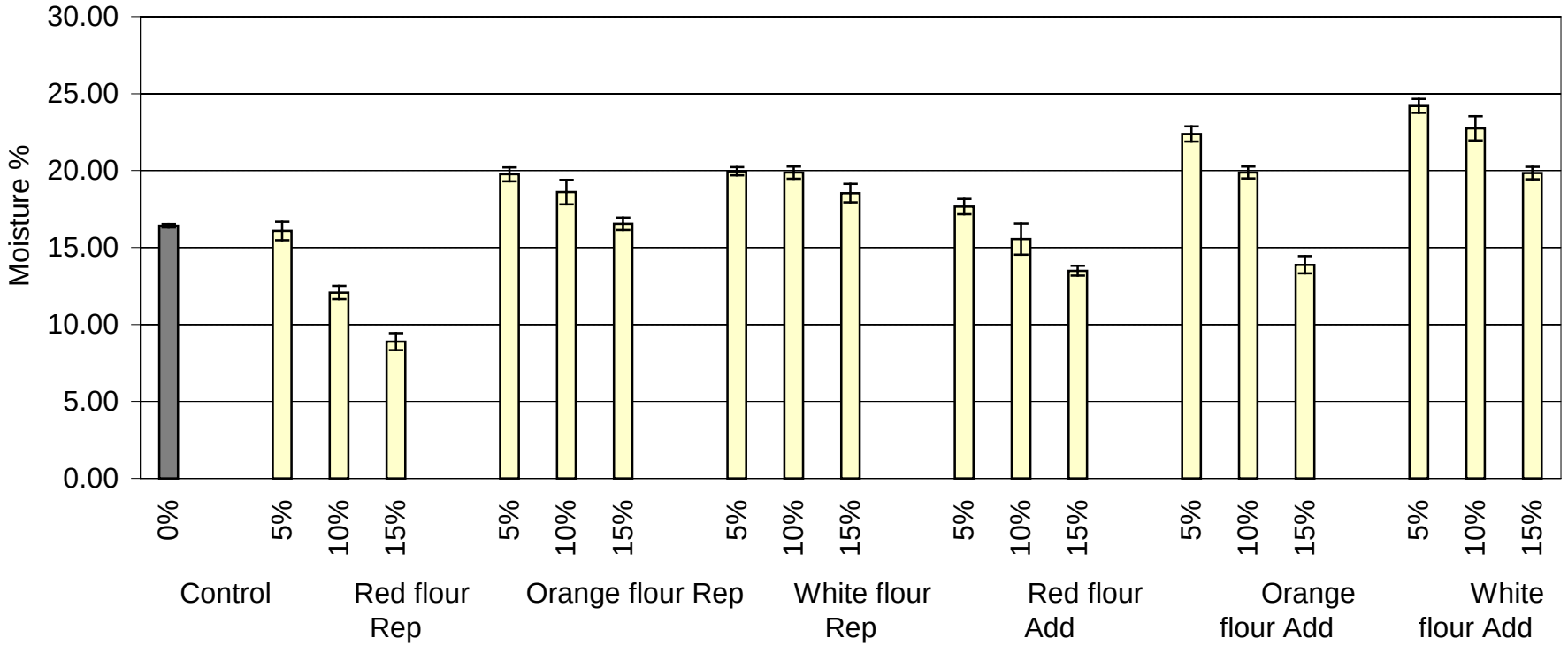


Figure 5.2: Sweet-potato flour effect on moisture content of bread

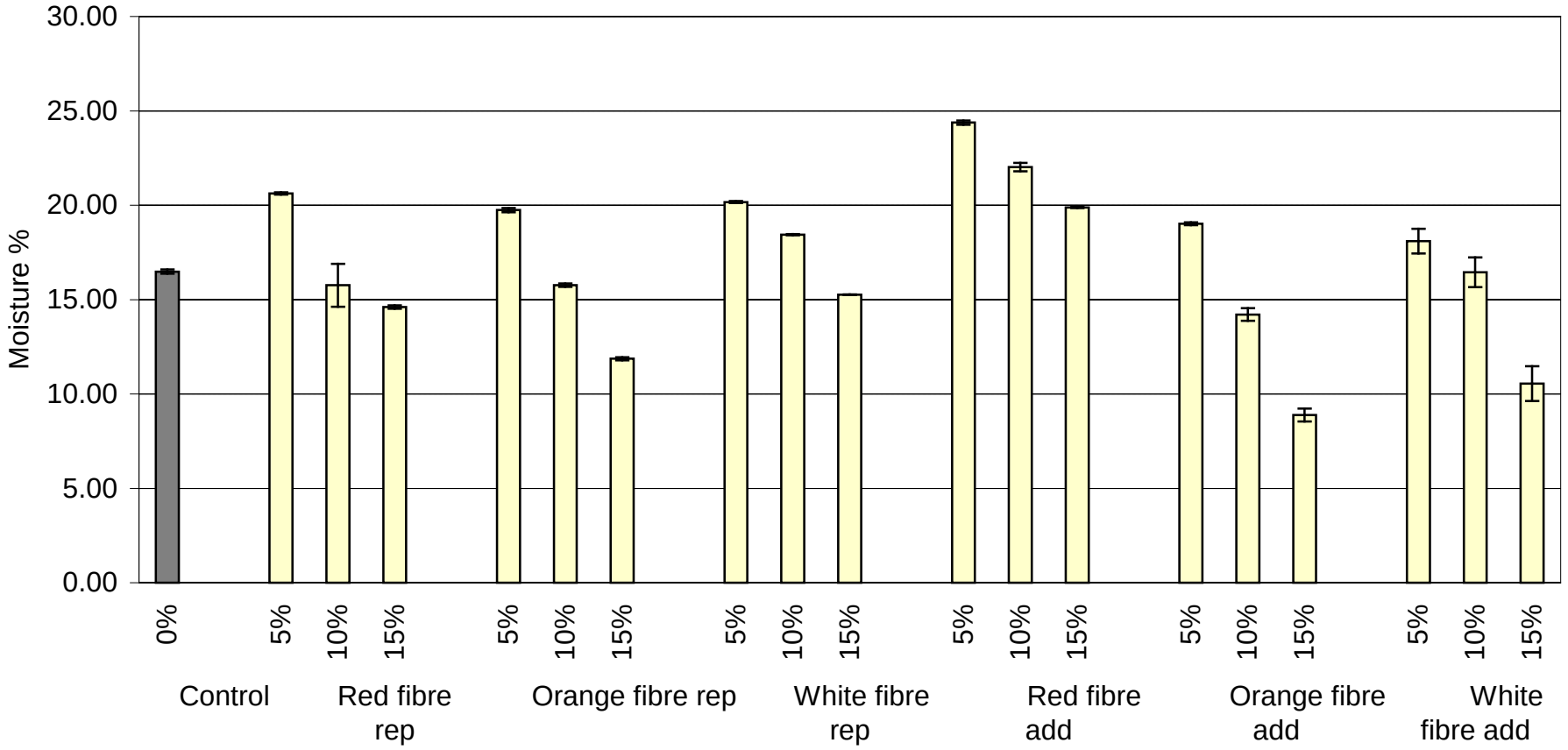


Figure 5.3: Sweet-potato fibre effect on moisture content of bread

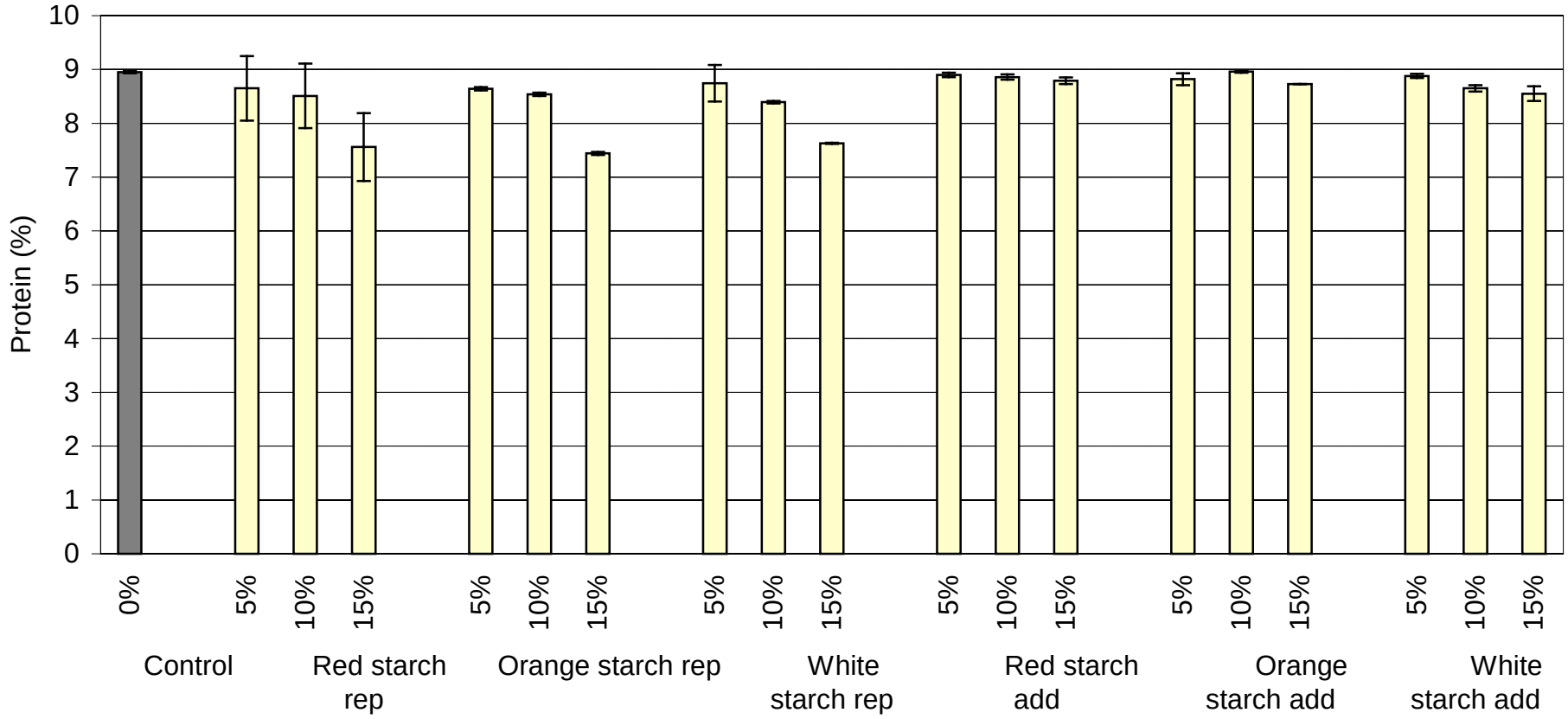


Figure 5.4: Sweet-potato starch effect on protein of bread

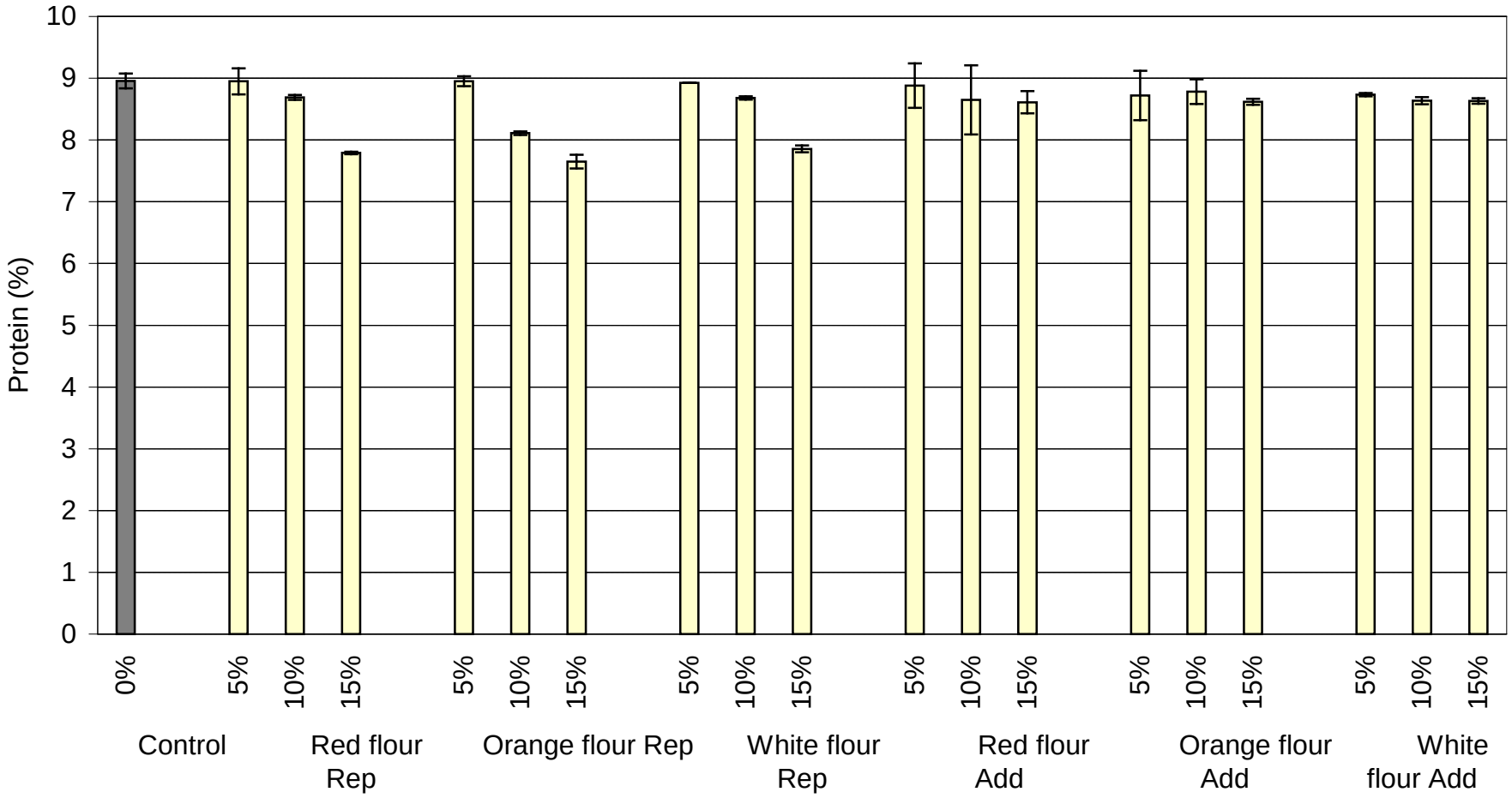


Figure 5.5: Sweet-potato flour effect on protein of bread

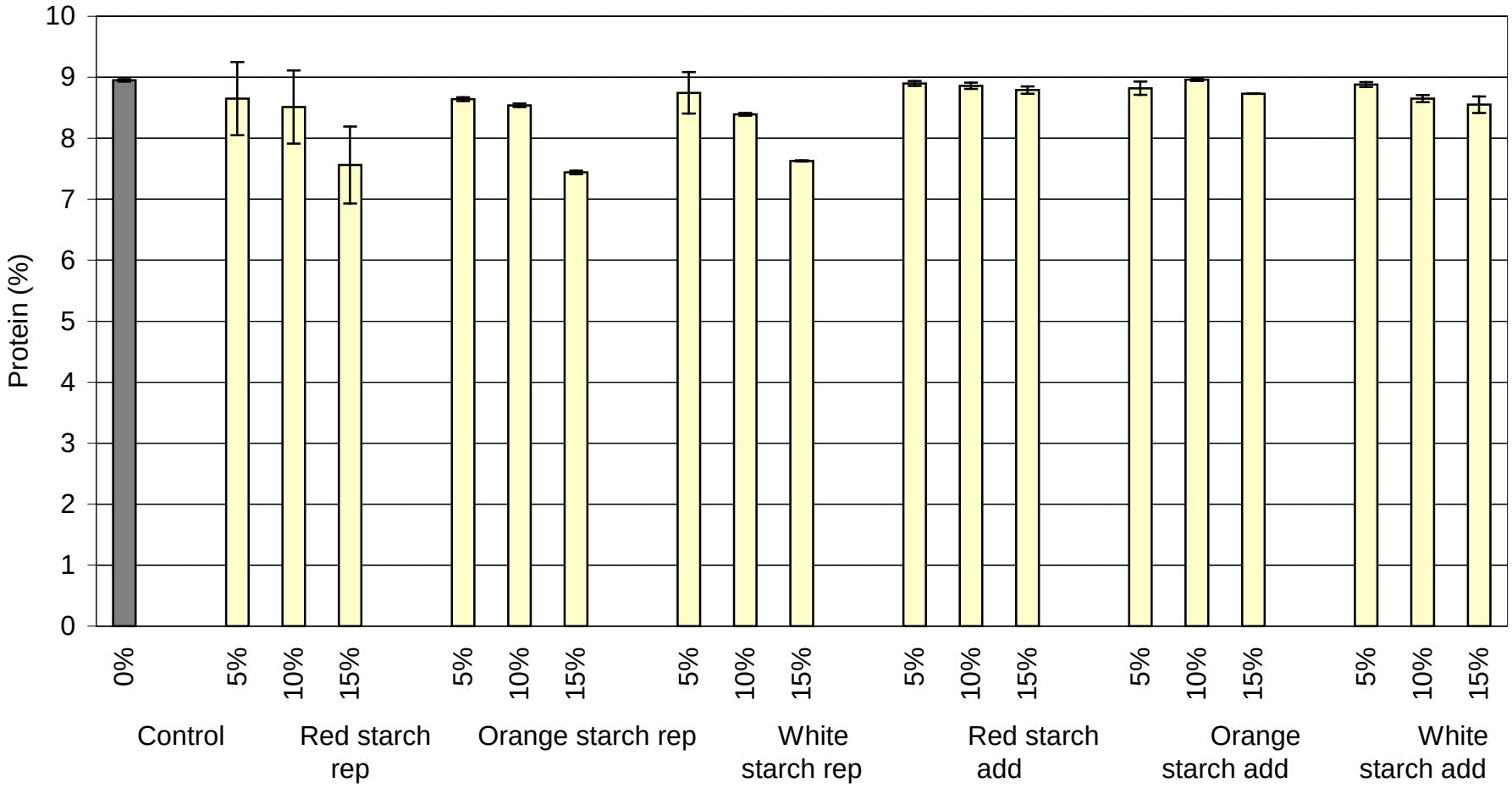


Figure 5.6: Sweet-potato fibre effect on protein of bread

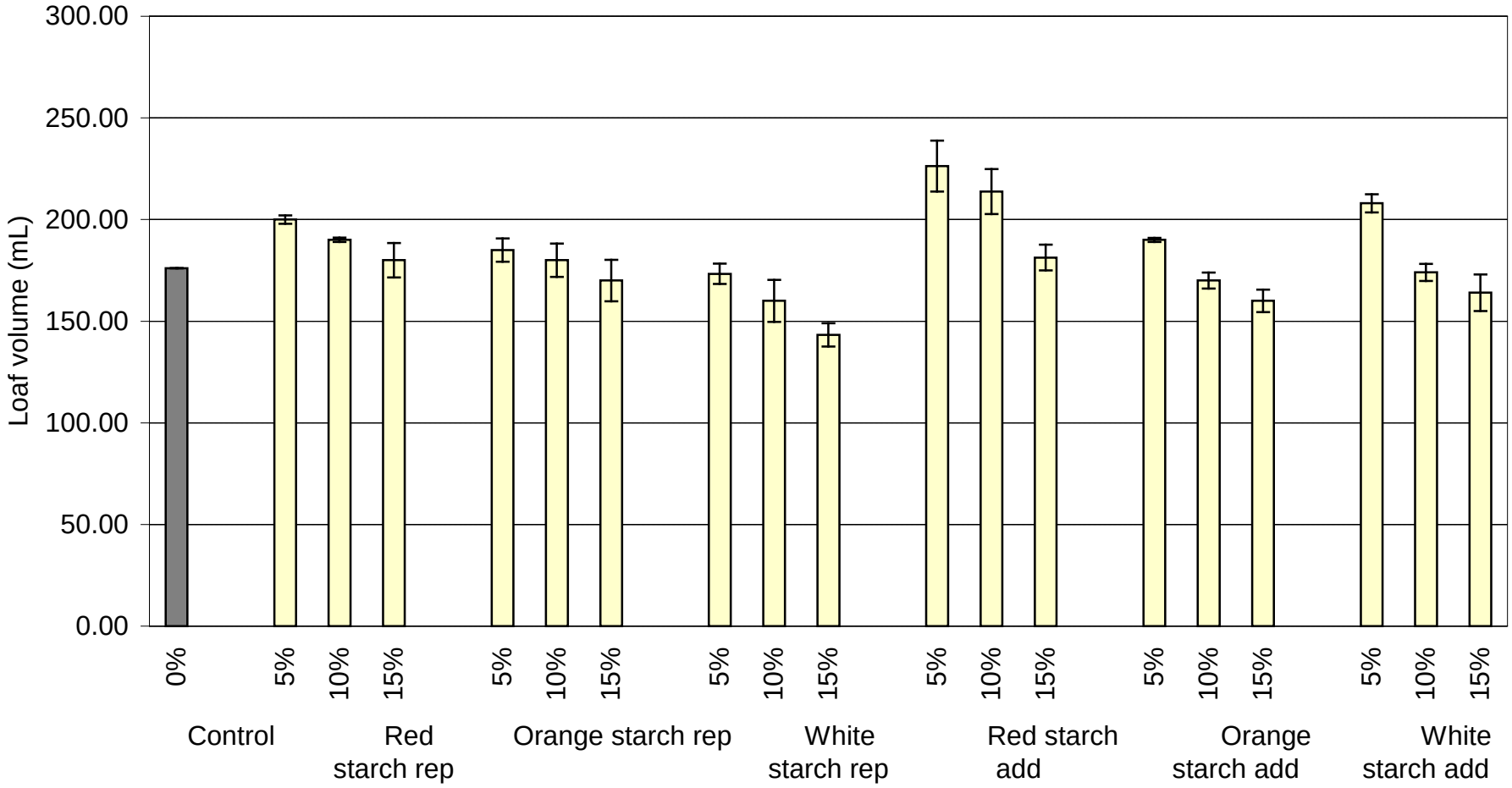


Figure 5.7: Sweet-potato starch effect on volume of bread

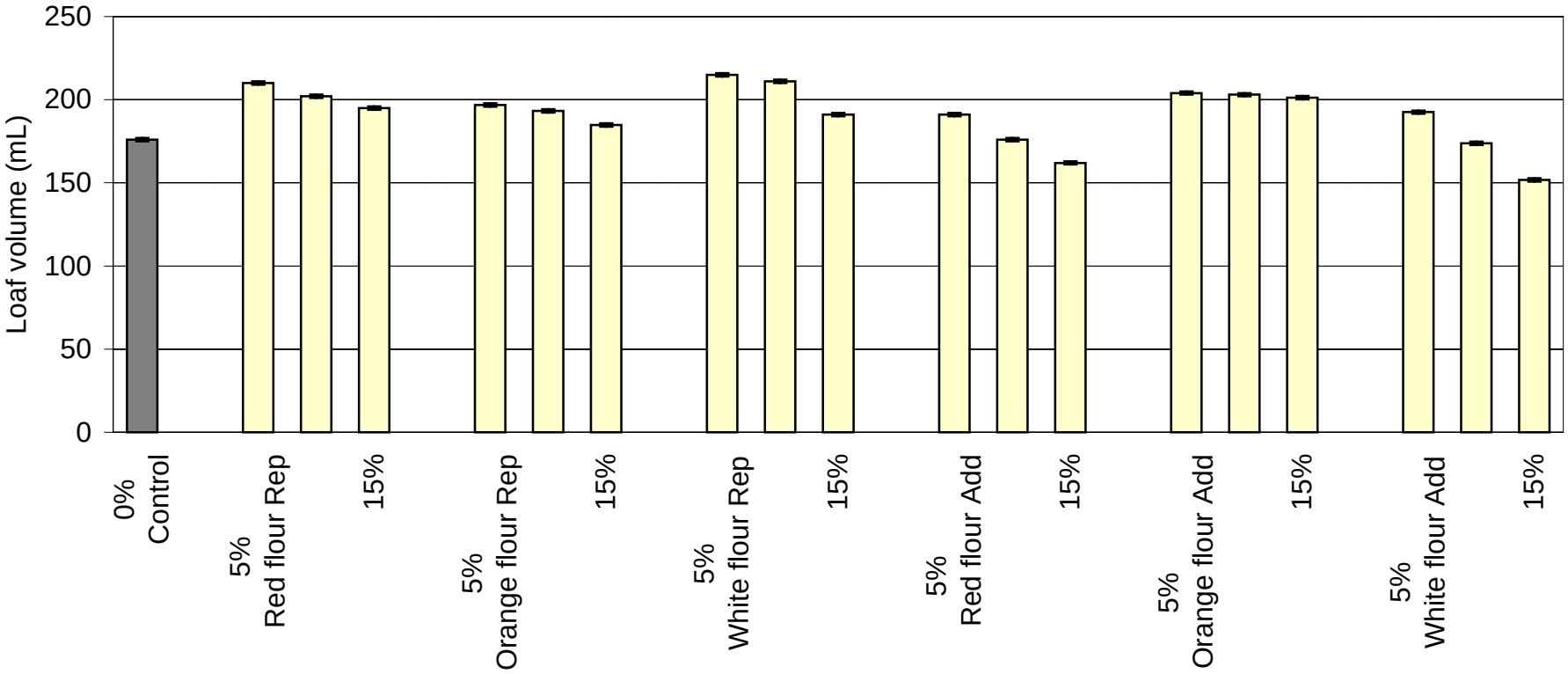


Figure 5.8: Sweet-potato flour effect on volume of bread

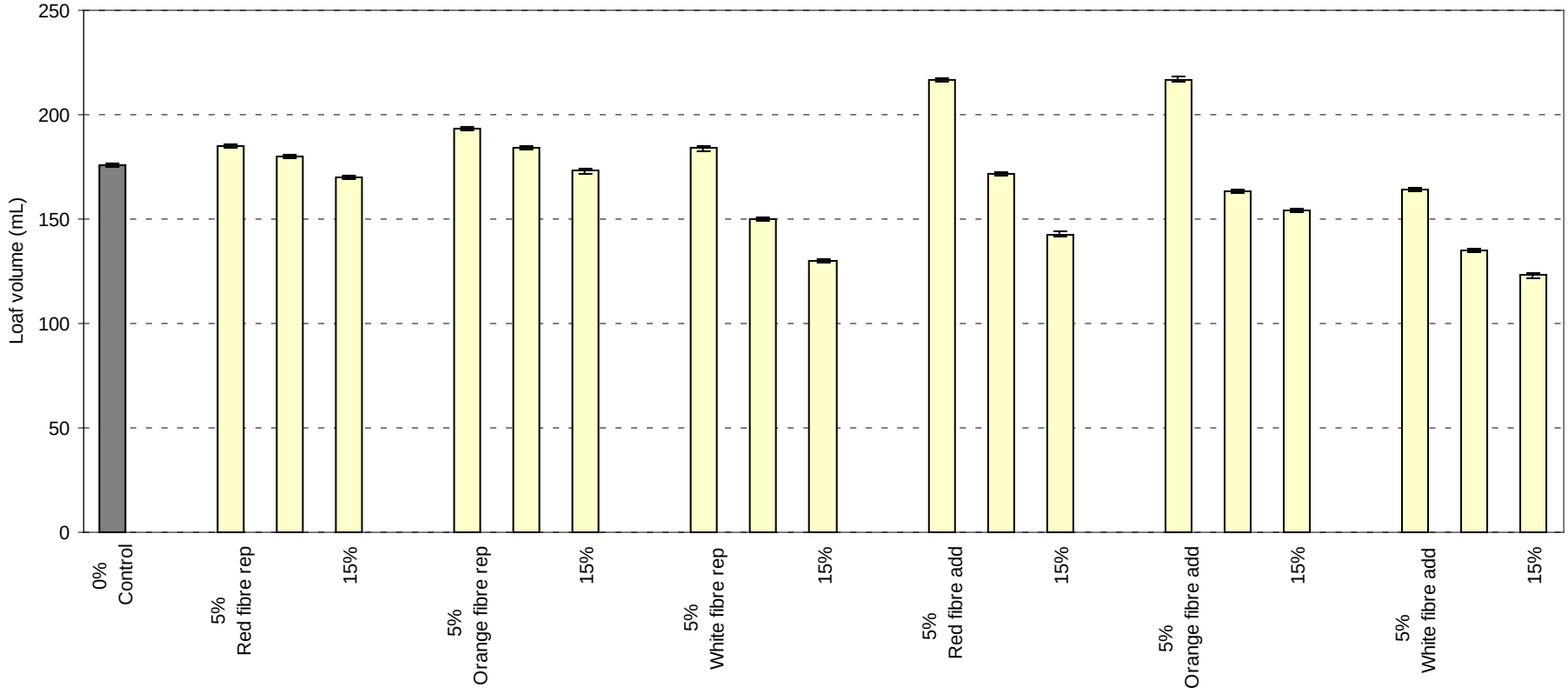


Figure 5.9: Sweet-potato fibre effect on volume of bread

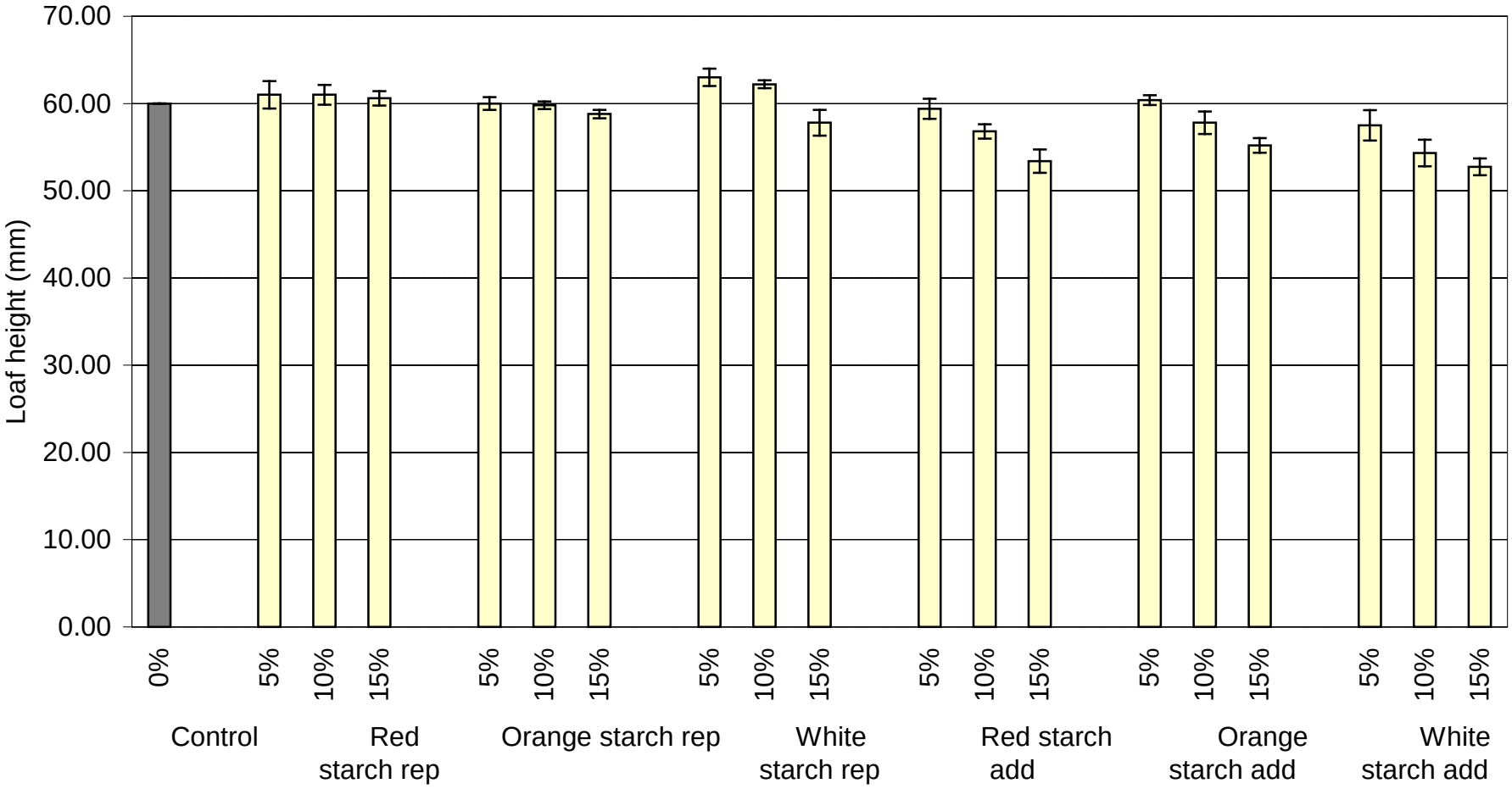


Figure 5.10: Sweet-potato starch effect on height of bread

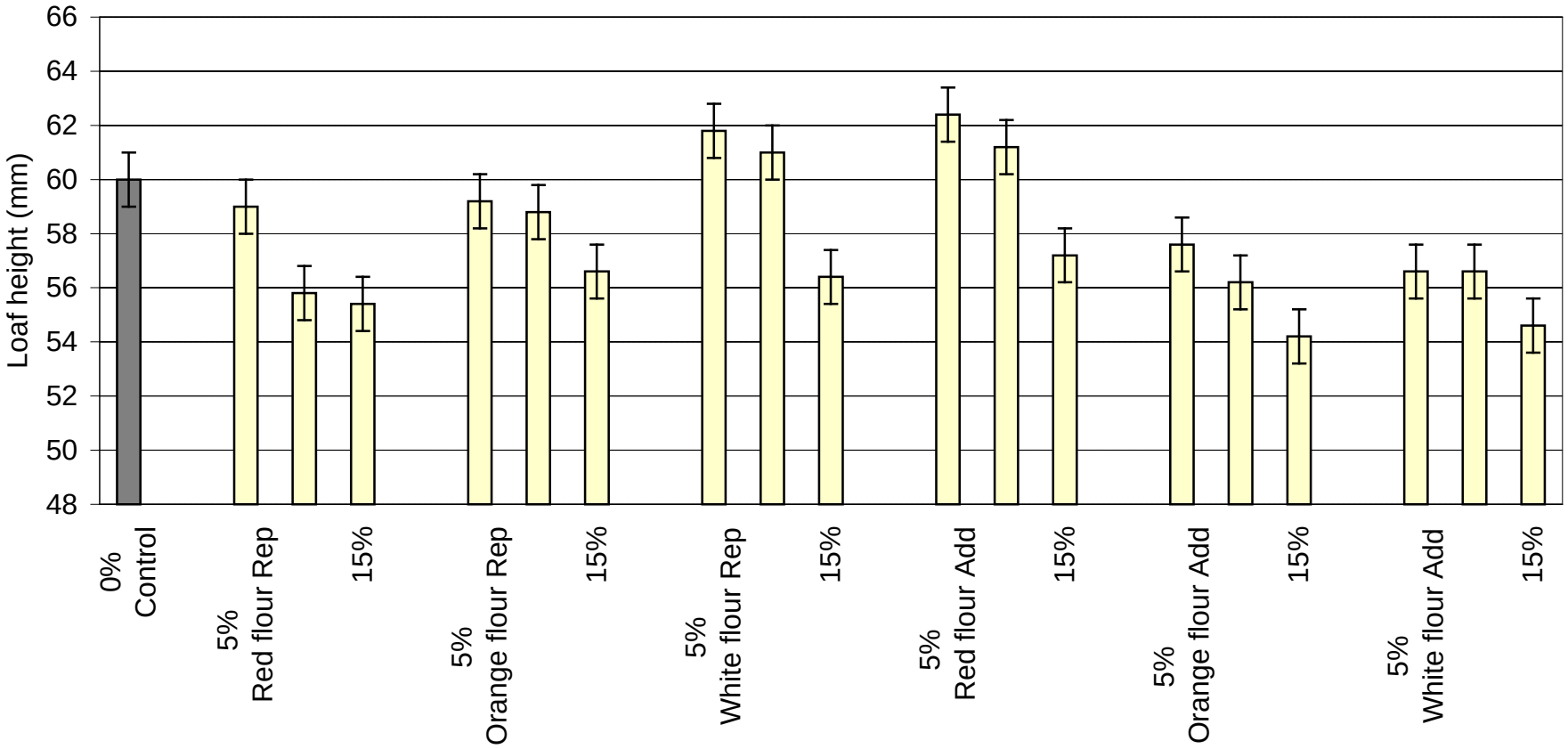


Figure 5.11: Sweet-potato flour effect on height of bread

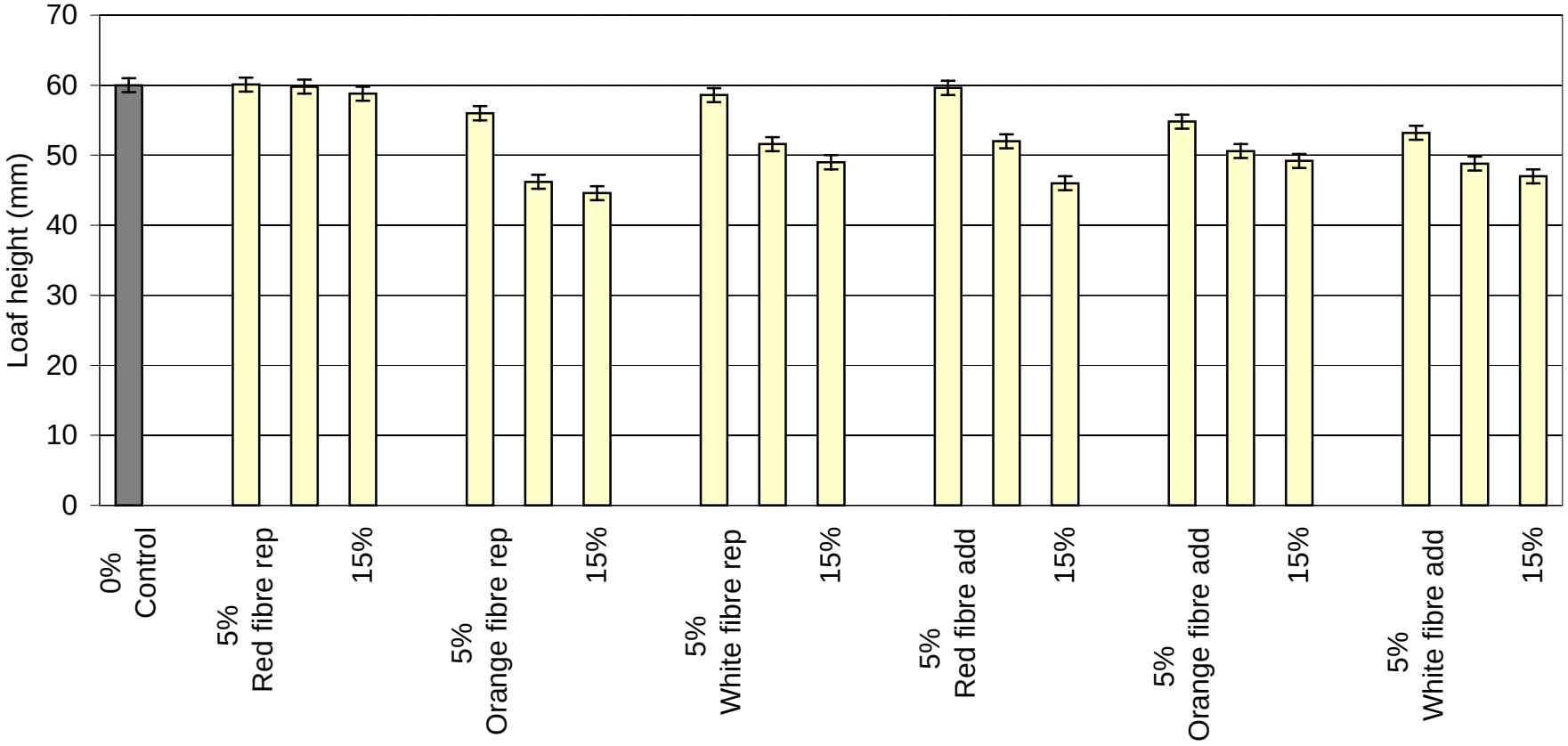


Figure 5.12: Sweet-potato fibre effect on height of bread

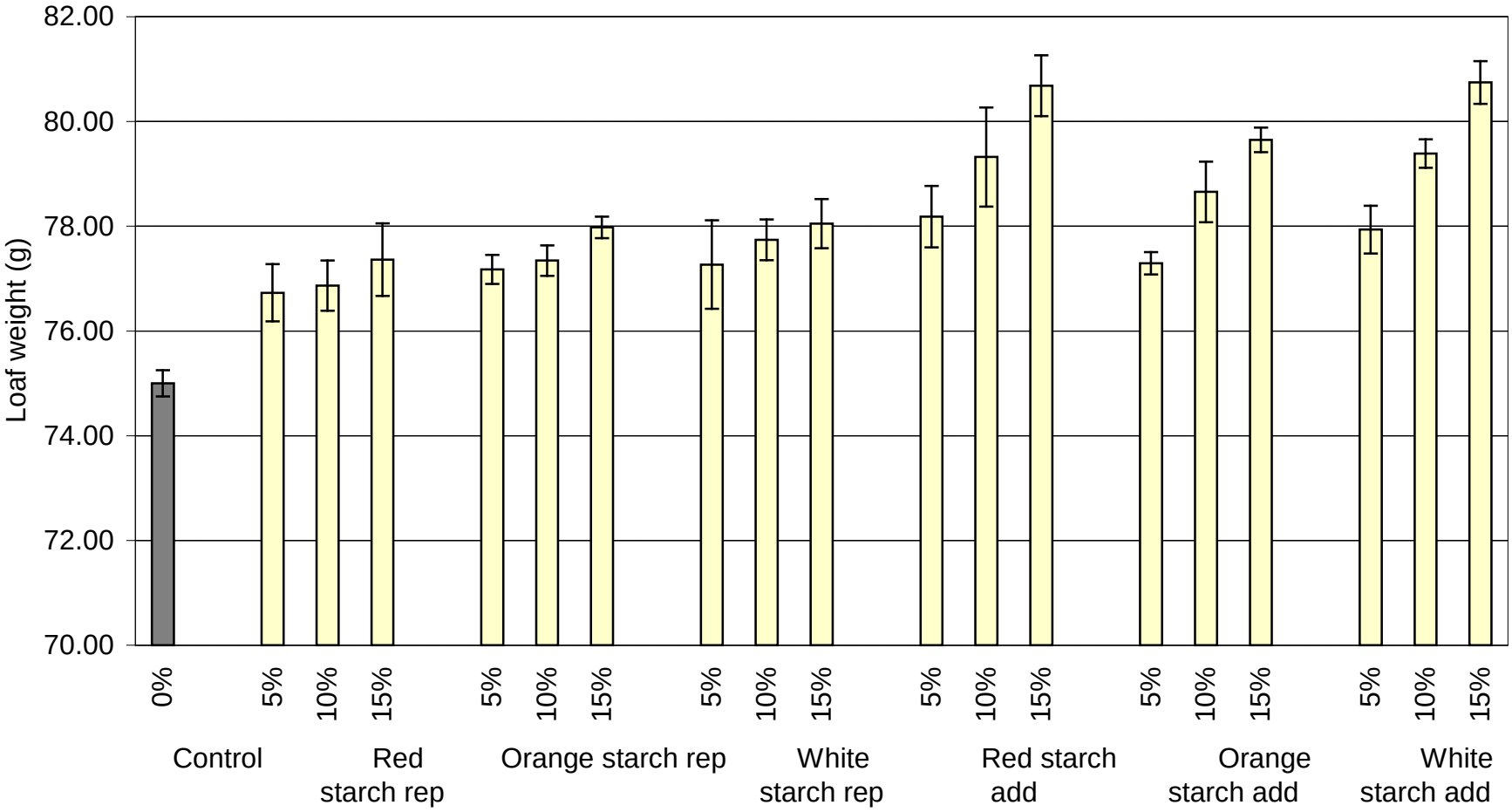


Figure 5.13: Sweet-potato starch effect on weight of bread

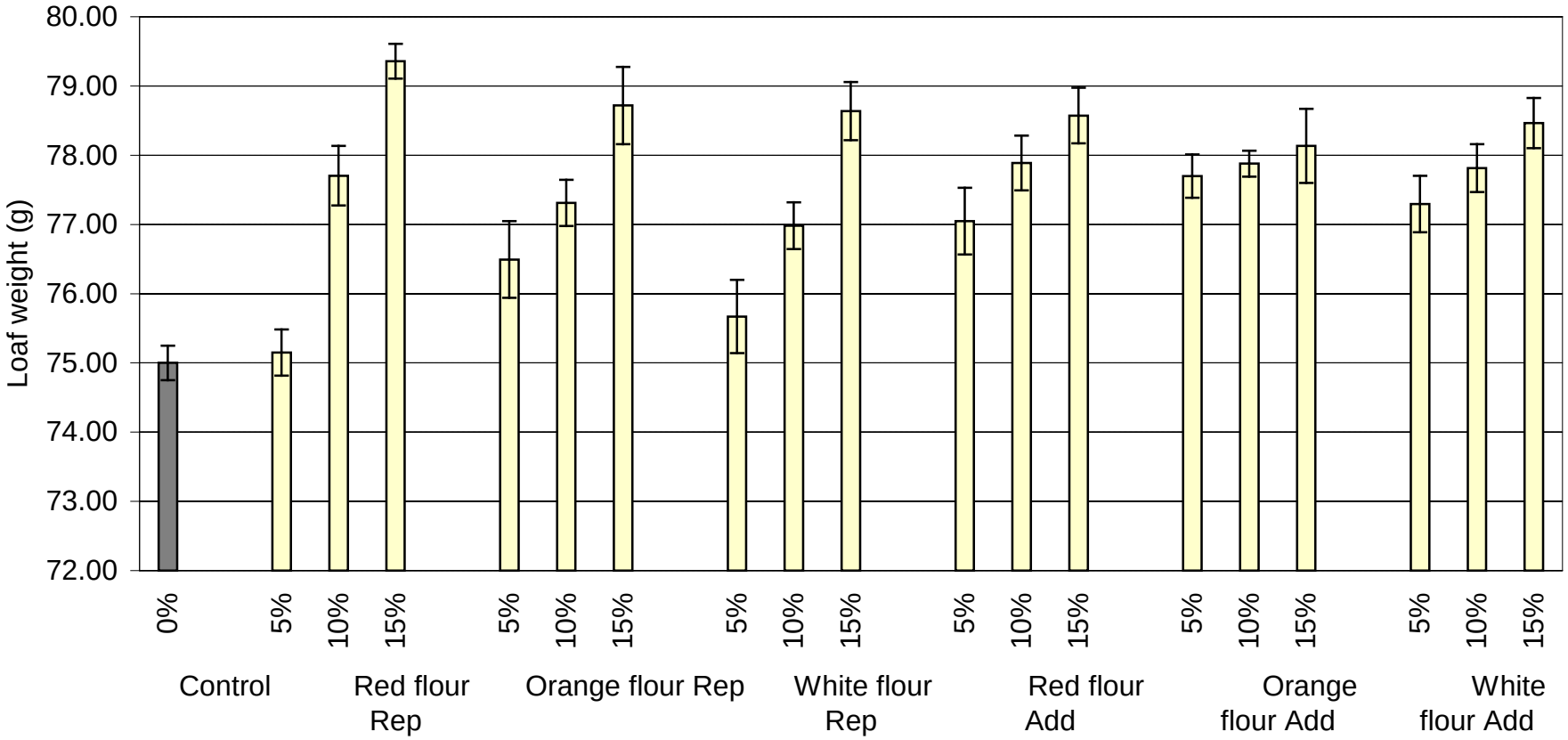


Figure 5.14: Sweet-potato flour effect on weight of bread

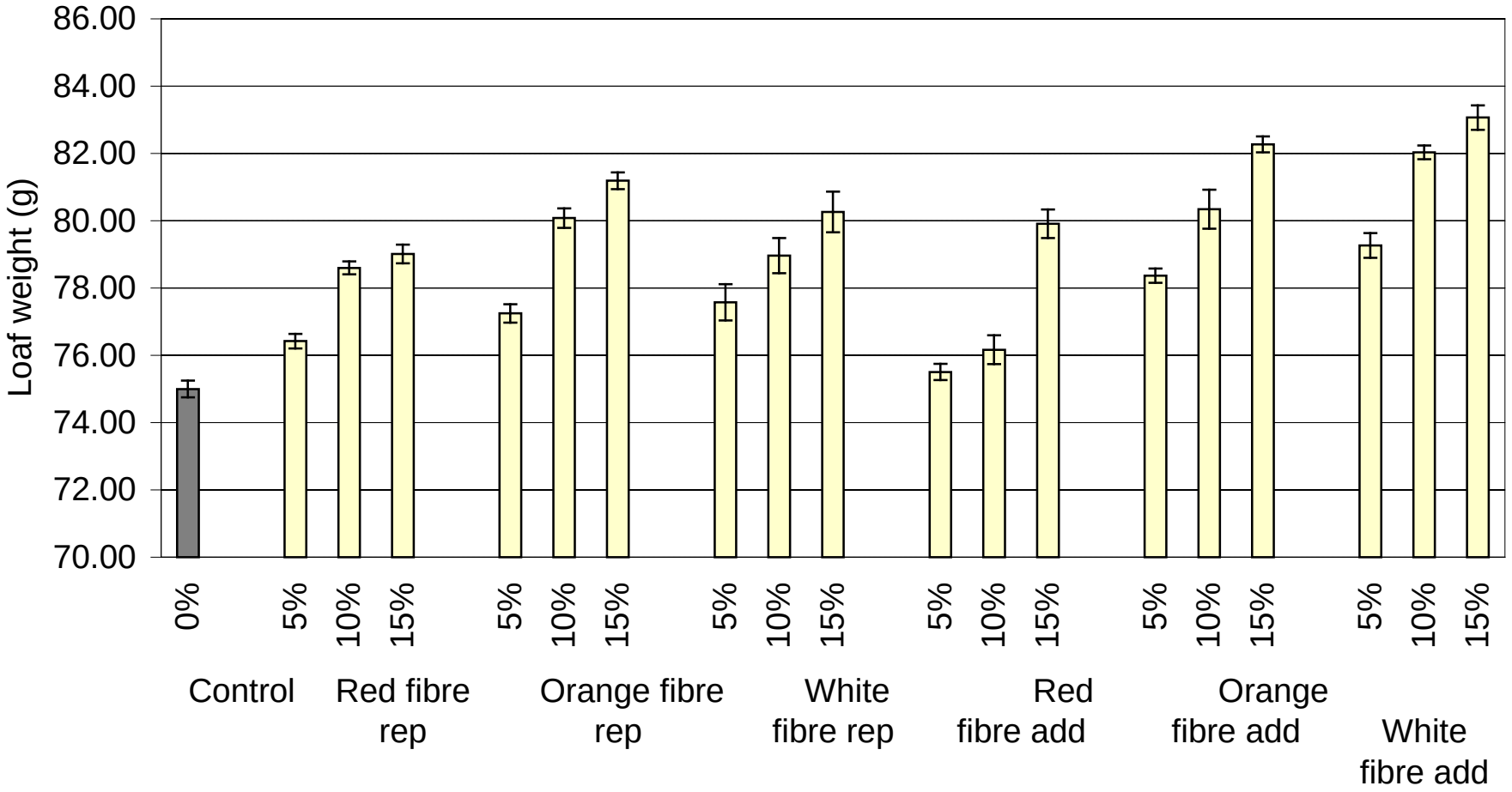


Figure 5.15: Sweet-potato fibre effect on weight of bread

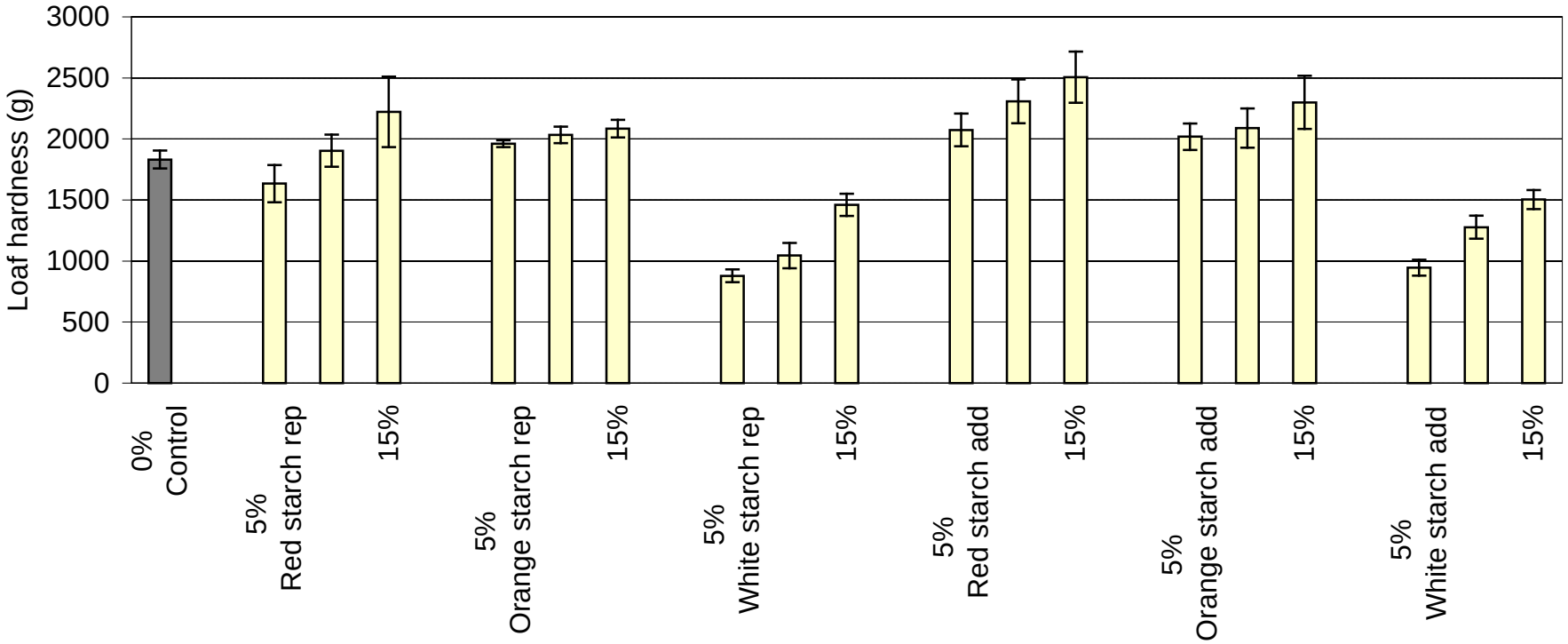


Figure 5.16: Sweet-potato starch effect on hardness of bread

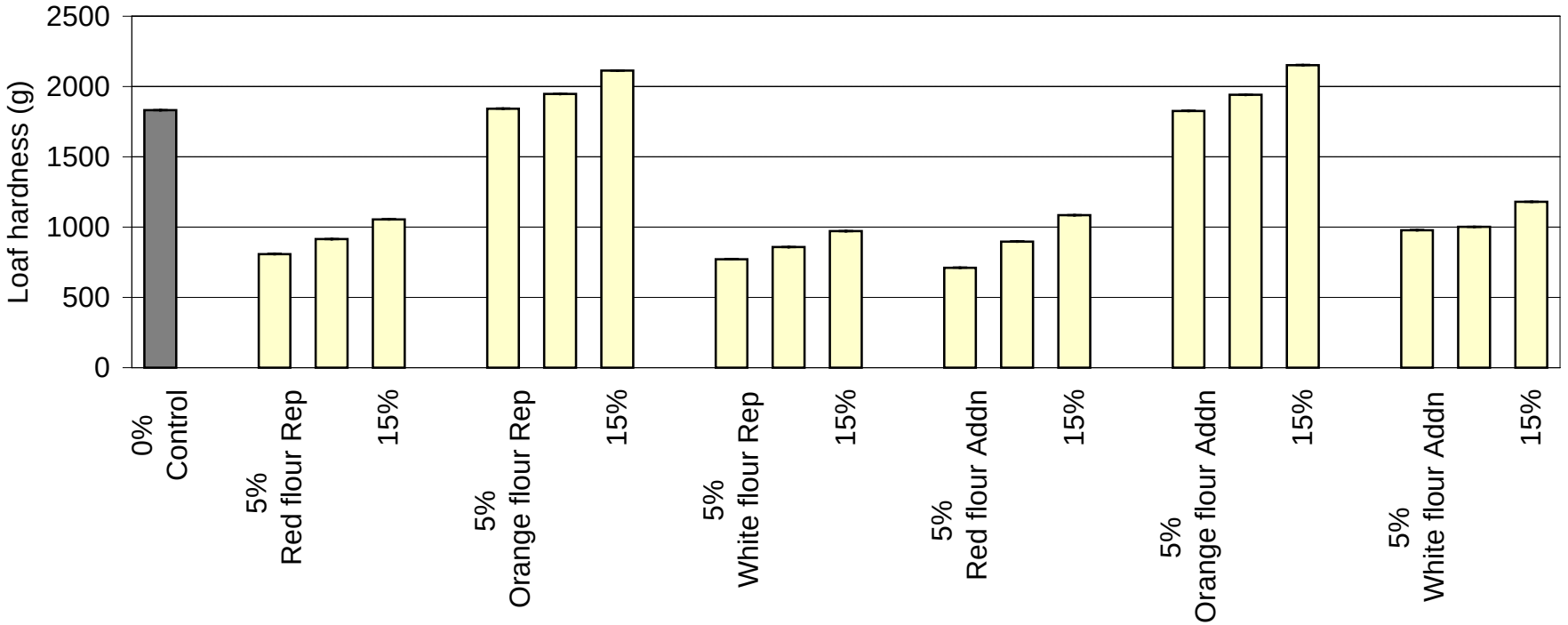


Figure 5.17: Sweet-potato flour effect on hardness of bread

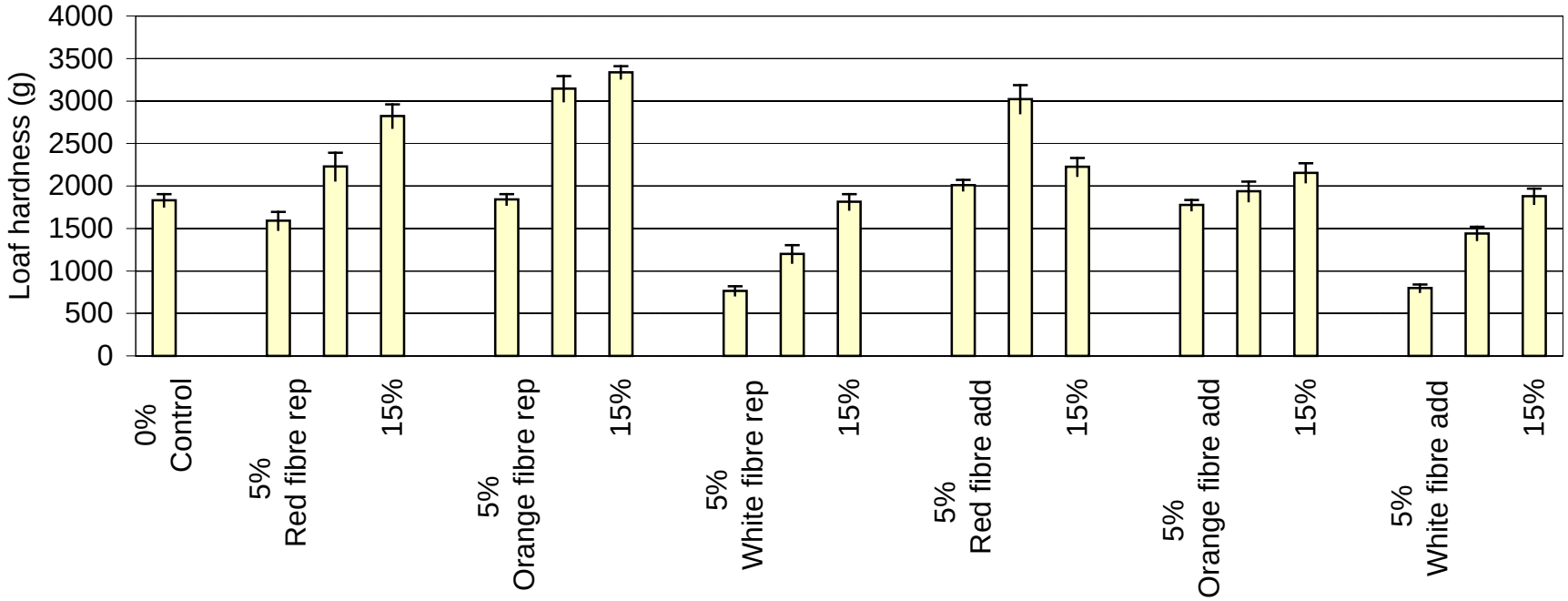


Figure 5.18: Sweet-potato fibre effect on hardness of bread

Tables 5.1: Sweet-potato starch effect on the physical properties of bread

Bread	Level	Mode	Moisture %	Protein %	Height mm	Volume mL	Weight g	Density ml/g	Hardness g
Control	0%	0	16.48 ± 0.0 c	8.95 ± 0.0 c	60.00 ± 0.01 b	176.00 ± 0.0 b	75.00 ± 0.3 a	2.35 ± 0.0 d	1831.29 ± 73 e
Red starch	5%	replacement	18.15 ± 2.2 c	8.65 ± 0.6 b	61.00 ± 1.58 b	200.00 ± 2.1 c	76.73 ± 0.5 b	2.59 ± 2.2 f	1634.30 ± 152 d
	10%	replacement	12.79 ± 0.2 a	8.51 ± 0.6 b	60.80 ± 1.14 b	190.00 ± 1.1 c	76.87 ± 0.5 b	2.47 ± 0.2 e	1904.03 ± 132 e
	15%	replacement	10.64 ± 0.0 b	7.56 ± 0.6 a	60.60 ± 0.83 b	180.00 ± 8.4 bc	77.36 ± 0.7 c	2.35 ± 0.0 d	2222.48 ± 289 h
Orange starch	5%	replacement	18.02 ± 1.2 c	8.64 ± 0.0 b	60.00 ± 0.74 b	185.00 ± 5.8 bc	77.17 ± 0.3 c	2.40 ± 1.2 e	1960.85 ± 28 ef
	10%	replacement	17.88 ± 0.3 c	8.54 ± 0.0 b	59.40 ± 0.45 b	180.00 ± 8.2 bc	77.35 ± 0.3 c	2.33 ± 0.3 d	2033.41 ± 68 f
	15%	replacement	13.43 ± 1.0 a	7.44 ± 0.0 a	58.80 ± 0.48 b	170.00 ± 10.2 acd	77.98 ± 0.2 d	2.18 ± 1.0 d	2084.17 ± 72 f
White starch	5%	replacement	18.10 ± 0.0 e	8.74 ± 0.3 bc	63.00 ± 1.00 d	173.30 ± 5.0 ab	77.27 ± 0.8 c	2.93 ± 0.0 h	878.97 ± 53 a
	10%	replacement	13.77 ± 2.2 d	8.39 ± 0.0 b	61.20 ± 0.45 b	160.00 ± 10.3 b	77.74 ± 0.4 cd	2.74 ± 2.2 g	1045.38 ± 104 b
	15%	replacement	10.44 ± 0.2 c	7.63 ± 0.0 a	57.80 ± 1.48 ab	143.30 ± 5.7 a	78.05 ± 0.5 d	2.35 ± 0.2 d	1460.56 ± 91 c
Red starch	5%	addition	24.16 ± 0.1 e	8.90 ± 0.0 c	59.40 ± 1.14 b	226.30 ± 12.5 e	78.18 ± 0.6 d	2.15 ± 0.1 c	2073.50 ± 134 f
	10%	addition	22.39 ± 0.3 d	8.86 ± 0.1 c	56.80 ± 0.83 a	213.80 ± 11.1 d	79.32 ± 0.9 c	2.02 ± 0.3 b	2308.77 ± 180 fg
	15%	addition	17.29 ± 0.0 c	8.79 ± 0.1 c	53.40 ± 1.34 c	181.30 ± 6.3 acd	80.68 ± 0.6 f	1.83 ± 0.0 a	2507.27 ± 210 g
Orange starch	5%	addition	21.54 ± 0.3 d	8.82 ± 0.1 c	60.40 ± 0.56 b	190.00 ± 1.0 c	77.29 ± 0.2 c	2.46 ± 0.3 e	2018.77 ± 109 f
	10%	addition	20.77 ± 0.2 d	8.96 ± 0.0 c	57.80 ± 0.84 ab	170.00 ± 3.9 b	78.66 ± 0.6 de	2.20 ± 0.2 c	2089.96 ± 161 ef
	15%	addition	17.97 ± 0.2 c	8.73 ± 0.0 bc	55.20 ± 1.30 a	160.00 ± 5.5 ab	79.65 ± 0.2 ef	2.01 ± 0.2 b	2299.52 ± 218 fg
White starch	5%	addition	22.91 ± 1.2 de	8.88 ± 0.0 c	57.50 ± 1.73 ab	208.00 ± 4.5 c	77.94 ± 0.5 d	2.67 ± 1.2 g	946.41 ± 65 b
	10%	addition	22.65 ± 0.3 de	8.65 ± 0.1 c	54.33 ± 1.53 a	174.00 ± 4.2 ab	79.39 ± 0.3 de	2.19 ± 0.3 b	1277.23 ± 94 c
	15%	addition	21.28 ± 1.0 d	8.55 ± 0.1 b	52.75 ± 0.96 c	164.00 ± 8.9 ab	80.75 ± 0.4 f	2.03 ± 1.0 b	1504.17 ± 78 c

Mean of 5 different samples (and S.D). Mean separation within column by Tukey's Multiply range test (5% level).
Each attribute means different letter are significant different (p≤0.05).

Tables 5.2: Sweet-potato flour effect on the physical properties of bread

Bread	Level	Mode	Moisture %	Protein %	Height mm	Volume mL	Weight g	Density ml/g	Hardness g
Control	0%	0	16.48 ± 0.1 d	8.96 ± 0.1 c	60.00 ± 0.00 b	176.00 ± 0.0 c	75.00 ± 0.3 a	2.35 ± 0.0 c	1831.29 ± 73.3 d
Red flour	5%	replacement	16.08 ± 0.6 d	8.95 ± 0.2 c	59.00 ± 1.14 ab	210.00 ± 1.5 f	75.15 ± 0.3 a	2.80 ± 2.2 f	808.09 ± 49.0 ab
	10%	replacement	12.08 ± 0.4 b	8.69 ± 0.0 b	55.80 ± 1.92 a	202.00 ± 1.5 e	77.70 ± 0.4 c	2.60 ± 0.2 ef	914.78 ± 42.5 c
	15%	replacement	8.89 ± 0.6 a	7.79 ± 0.0 a	55.40 ± 1.55 a	195.00 ± 0.0 d	79.36 ± 0.3 f	2.43 ± 0.0 d	1055.16 ± 48.9 e
Orange flour	5%	replacement	19.76 ± 0.5 de	8.95 ± 0.1 c	59.20 ± 1.14 b	196.80 ± 5.8 de	76.49 ± 0.6 b	2.56 ± 1.2 e	1842.35 ± 26.2 d
	10%	replacement	18.60 ± 0.8 e	8.11 ± 0.0 b	58.80 ± 1.30 ab	193.20 ± 8.2 de	77.31 ± 0.3 c	2.50 ± 0.3 e	1946.63 ± 118 de
	15%	replacement	16.55 ± 0.4 d	7.65 ± 0.1 a	56.60 ± 0.84 ab	184.80 ± 0.0 d	78.72 ± 0.6 e	2.37 ± 1.0 c	2112.81 ± 49.4 e
White flour	5%	replacement	19.96 ± 0.3 de	8.92 ± 0.0 c	61.80 ± 1.52 bc	215.00 ± 2.2 f	75.67 ± 0.5 c	2.84 ± 0.0 f	771.72 ± 42.0 a
	10%	replacement	19.87 ± 0.4 de	8.68 ± 0.0 b	61.00 ± 0.71 bc	211.00 ± 1.5 f	76.98 ± 0.3 d	2.71 ± 2.2 ef	857.41 ± 61.8 b
	15%	replacement	18.54 ± 0.6 e	7.86 ± 0.1 a	56.40 ± 1.30 a	191.00 ± 3.5 d	78.64 ± 0.4 e	2.52 ± 0.2 e	970.98 ± 34.0 c
Red flour	5%	addition	17.67 ± 0.5 e	8.88 ± 0.4 c	62.40 ± 1.67 c	191.00 ± 0.0 d	77.05 ± 0.5 c	2.48 ± 0.1 d	711.15 ± 119 a
	10%	addition	15.55 ± 1.0 c	8.65 ± 0.6 b	61.20 ± 1.09 bc	176.00 ± 0.0 c	77.89 ± 0.4 d	2.26 ± 0.3 b	897.26 ± 81.4 b
	15%	addition	13.50 ± 0.3 b	8.61 ± 0.2 b	57.20 ± 1.30 ab	162.00 ± 0.0 b	78.57 ± 0.4 e	2.04 ± 0.0 a	1084.64 ± 175 bc
Orange flour	5%	addition	22.38 ± 0.5 f	8.72 ± 0.4 c	57.60 ± 1.14 ab	204.00 ± 15.2 df	77.70 ± 0.3 d	2.63 ± 0.3 ef	1826.05 ± 22.9 d
	10%	addition	19.88 ± 0.4 de	8.78 ± 0.2 c	56.20 ± 1.79 ab	203.00 ± 5.7 d	77.88 ± 0.2 d	2.60 ± 0.2 e	1940.74 ± 125 de
	15%	addition	13.88 ± 0.6 b	8.62 ± 0.1 b	54.20 ± 4.27 ab	201.20 ± 8.8 d	78.13 ± 0.5 e	2.58 ± 0.2 e	2152.75 ± 84.1 e
White flour	5%	addition	24.21 ± 0.5 g	8.73 ± 0.0 bc	56.60 ± 1.14 ab	192.50 ± 8.7 de	77.30 ± 0.4 c	2.49 ± 1.2 de	978.09 ± 54.4 b
	10%	addition	22.75 ± 0.8 f	8.64 ± 0.1 b	56.60 ± 0.89 ab	173.80 ± 4.8 c	77.81 ± 0.3 d	2.22 ± 0.3 b	1001.89 ± 81.7 bc
	15%	addition	19.84 ± 0.4 de	8.63 ± 0.0 b	54.60 ± 1.52 a	151.80 ± 2.5 a	78.47 ± 0.4 e	1.95 ± 1.0 a	1180.17 ± 75.6 cd

Mean of 5 different samples (and S.D). Mean separation within column by Tukey's Multiply range test (5% level).

Each attribute means different letter are significant different ($p \leq 0.05$).

Tables 5.3: Sweet-potato fibre effect on the physical properties of bread

Bread	Level	Mode	Moisture %	Protein %	Height mm	Volume mL	Weight g	Density mg/g	Hardness g
Control	0%	0	16.48 ± 0.1 d	8.95 ± 0.0 d	60.00 ± 0.00 c	176.00 ± 0.0 e	75.00 ± 0.3 a	2.35 ± 0.0 e	1831.29 ± 73.0 c
Red fibre	5%	replacement	20.63 ± 0.1 e	8.82 ± 0.06 d	60.10 ± 0.71 c	185.00 ± 0.0 g	76.42 ± 0.2 ab	2.36 ± 2.2 e	1590.97 ± 105 b
	10%	replacement	15.76 ± 1.1 cd	8.60 ± 0.03 c	59.80 ± 0.84 c	180.00 ± 0.0 f	78.60 ± 0.2 bc	2.29 ± 0.2 d	2228.48 ± 162 d
	15%	replacement	14.60 ± 0.1 c	8.04 ± 0.08 a	58.80 ± 0.89 bc	170.00 ± 0.0 d	79.01 ± 0.3 bc	2.15 ± 0.0 cd	2823.02 ± 138 e
Orange fibre	5%	replacement	19.74 ± 0.1 e	8.78 ± 0.03 c	56.00 ± 1.15 b	193.30 ± 2.8 h	77.25 ± 0.3 b	2.50 ± 1.2 f	1841.85 ± 61.6 c
	10%	replacement	15.76 ± 0.1 cd	8.27 ± 0.07 b	46.20 ± 0.84 a	184.00 ± 1.2 g	80.08 ± 0.3 c	2.30 ± 0.3 d	3145.45 ± 147 e
	15%	replacement	11.87 ± 0.1 b	8.15 ± 0.38 a	44.60 ± 2.70 a	173.00 ± 0.0 de	81.19 ± 0.2 c	2.13 ± 1.0 cd	3338.20 ± 71.3 e
			±	±	±	±	±	±	±
White fibre	5%	replacement	20.17 ± 0.1 e	8.80 ± 0.05 d	58.60 ± 0.89 bc	183.80 ± 1.5 g	77.58 ± 0.5 b	2.37 ± 0.0 e	765.53 ± 53.2 a
	10%	replacement	18.44 ± 0.0 de	8.50 ± 0.03 bc	51.60 ± 1.34 b	150.00 ± 1.1 c	78.96 ± 0.5 bc	1.90 ± 2.2 b	1200.35 ± 104 ab
	15%	replacement	15.26 ± 0.0 c	8.29 ± 0.00 a	49.00 ± 1.22 b	130.00 ± 6.3 b	80.26 ± 0.6 c	1.64 ± 0.2 a	1813.35 ± 91.2 c
Red fibre	5%	addition	24.38 ± 0.1 f	8.72 ± 0.01 cd	59.62 ± 0.55 c	216.80 ± 1.0 j	75.50 ± 0.2 a	2.91 ± 0.1 f	2009.43 ± 62.4 d
	10%	addition	22.02 ± 0.2 ef	8.65 ± 0.01 c	52.00 ± 0.00 b	171.50 ± 0.2 d	76.17 ± 0.4 ab	2.25 ± 0.3 d	3022.04 ± 164 e
	15%	addition	19.88 ± 0.0 e	8.56 ± 0.17 bc	46.00 ± 1.00 a	142.80 ± 0.5 c	79.91 ± 0.4 c	1.79 ± 0.0 b	2224.92 ± 106 d
Orange fibre	5%	addition	19.02 ± 0.1 e	8.76 ± 0.02 cd	54.80 ± 2.49 b	217.00 ± 0.6 b	78.36 ± 0.2 b	2.77 ± 0.3 df	1776.02 ± 60.5 bc
	10%	addition	14.21 ± 0.3 c	8.70 ± 0.01 cd	50.60 ± 0.89 ab	163.50 ± 0.3 cd	80.34 ± 0.6 c	2.04 ± 0.2 c	1937.12 ± 115 c
	15%	addition	8.88 ± 0.3 a	8.64 ± 0.49 c	49.20 ± 1.30 ab	154.00 ± 1.0 c	82.27 ± 0.2 d	1.87 ± 0.2 b	2155.40 ± 111 d
White fibre	5%	addition	18.10 ± 0.7 e	8.45 ± 0.82 a	53.20 ± 1.09 b	164.00 ± 1.5 cd	79.26 ± 0.4 bc	2.07 ± 1.2 c	798.25 ± 43.9 a
	10%	addition	16.45 ± 0.8 c	8.15 ± 0.17 a	48.80 ± 1.30 ab	135.00 ± 1.2 b	82.04 ± 0.2 d	1.69 ± 0.3 ab	1441.89 ± 77.8 b
	15%	addition	10.55 ± 0.9 b	8.20 ± 0.16 b	47.00 ± 1.87 a	123.00 ± 0.9 a	83.07 ± 0.4 f	1.50 ± 1.0 a	1880.86 ± 89.2 c

Mean of 5 different samples (and S.D). Mean separation within column by Tukey's Multiply range test (5% level).
Each attribute means different letter are significant different ($p \leq 0.05$).

Table 5. 4: Correlations of various sweet potato bread physical properties

1. RED STARCH REPLACEMENT

	Volume	Hardness	Height	Weight
Hardness	-0.135			
	0.632			
Height	-0.271	-0.025		
	0.328	0.931		
Weight	-0.952	0.013	0.354	
	0.000	0.963	0.195	
Specific loaf vol	1.000	-0.135	-0.271	-0.952
	*	0.632	0.328	0.000

2. RED STARCH ADDITION

	Volume	Hardness	Height	Weight
Hardness	0.645			
	0.009			
Height	-0.920	-0.605		
	0.000	0.017		
Weight	0.950	0.760	-0.925	
	0.000	0.001	0.000	
Specific loaf vol	-0.941	-0.772	0.925	-0.998
	0.000	0.001	0.000	0.000

3. ORANGE STARCH REPLACEMENT

	Volume	Hardness	Height	Weight
Hardness	-0.669			
	0.006			
Height	0.525	-0.523		
	0.045	0.046		
Weight	-0.989	0.619	-0.487	
	0.000	0.014	0.066	
Specific loaf vol	0.995	-0.656	0.496	-0.995
	0.000	0.008	0.060	0.000

4. ORANGE STARCH REPLACEMENT

	Volume	Hardness	Height	Weight
Hardness	-0.858			
	0.000			
Height	-0.206	-0.005		
	0.462	0.987		
Weight	-0.995	0.903	0.166	
	0.000	0.000	0.553	
Specific loaf vol	0.995	-0.904	-0.165	-1.000
	0.000	0.000	0.556	0.000

5. WHITE STARCH REPLACEMENT

	Volume	Hardness	Height	Weight
Hardness	-0.922			
	0.000			
Height	0.763	-0.861		
	0.001	0.000		
Weight	-0.873	0.872	-0.811	
	0.000	0.000	0.000	
Specific loaf vol	0.906	-0.960	0.908	-0.951
	0.000	0.000	0.000	0.000

6. WHITE STARCH ADDITION

	Volume	Hardness	Height	Weight
Hardness	-0.861			
	0.000			
Height	0.680	-0.706		
	0.005	0.003		
Weight	-0.914	0.967	-0.732	
	0.000	0.000	0.002	
Specific loaf vol	0.955	-0.937	0.654	-0.966
	0.000	0.000	0.008	0.000

7. RED FLOUR REPLACEMENT

	Harness	Height	Weight	Specific loaf vol
Height	-0.500			
	0.058			
Weight	0.744	-0.684		
	0.001	0.005		
Specific loaf vol	-0.750	0.652	-0.997	
	0.001	0.008	0.000	
Volume	-0.636	0.219	-0.752	0.773
	0.011	0.432	0.001	0.001

8. RED FLOUR ADDITION

	Harness	Height	Weight	Specific loaf vol
Height	-0.521			
	0.046			
Weight	0.713	-0.818		
	0.003	0.000		
Specific loaf vol	-0.713	0.835	-0.998	
	0.003	0.000	0.000	
Volume	-0.616	0.691	-0.855	0.855
	0.015	0.004	0.000	0.000

9. ORANGE FLOUR REPLACEMENT

	Harness	Height	Weight	Specific loaf vol
Height	-0.100			
	0.723			
Weight	0.417	-0.240		
	0.122	0.390		
Specific loaf vol	-0.390	0.225	-0.998	
	0.151	0.420	0.000	
Volume	-0.346	0.193	-0.878	0.880
	0.207	0.490	0.000	0.000

10. ORANGE FLOUR ADDITION

	Harness	Height	Weight	Specific loaf vol
Height	-0.188			
	0.503			
Weight	0.475	-0.719		
	0.073	0.003		
Specific loaf vol	-0.469	0.715	-1.000	
	0.078	0.003	0.000	
Volume	-0.339	0.310	-0.627	0.633
	0.217	0.260	0.012	0.011

11. WHITE FLOUR REPLACEMENT

	Harness	Height	Weight	Specific loaf vol
Height	-0.100			
	0.724			
Weight	0.888	-0.178		
	0.000	0.526		
Specific loaf vol	-0.843	0.255	-0.984	
	0.000	0.359	0.000	
Volume	-0.852	0.157	-0.787	0.792
	0.000	0.577	0.000	0.000

12. WHITE FLOUR ADDITION

	Harness	Height	Weight	Specific loaf vol
Height	-0.543			
	0.036			
Weight	0.983	-0.591		
	0.000	0.020		
Specific loaf vol	-0.977	0.569	-0.997	
	0.000	0.027	0.000	
Volume	-0.939	0.460	-0.958	0.956
	0.000	0.084	0.000	0.000

13. RED FIBRE REPLACEMENT

	Volume	Hardness	Height	Weight
Hardness	-0.850			
	0.000			
Height	0.877	-0.816		
	0.000	0.000		
Weight	-0.936	0.853	-0.830	
	0.000	0.000	0.000	
Specific loaf vol	0.895	-0.825	0.984	-0.844
	0.000	0.000	0.000	0.000

14. RED FIBRE ADDITION

	Volume	Hardness	Height	Weight
Hardness	0.014			
	0.963			
Height	0.990	0.068		
	0.000	0.817		
Weight	-0.866	-0.478	-0.895	
	0.000	0.084	0.000	
Specific loaf vol	0.994	0.064	0.994	-0.885
	0.000	0.829	0.000	0.000

15. ORANGE FIBRE REPLACEMENT

	Volume	Hardness	Height	Weight
Hardness	-0.912			
	0.000			
Height	0.988	-0.898		
	0.000	0.000		
Weight	-0.993	0.909	-0.980	
	0.000	0.000	0.000	
Specific loaf vol	0.956	-0.881	0.941	-0.984
	0.000	0.000	0.000	0.000

16. ORANGE FIBRE ADDITION

	Volume	Hardness	Height	Weight
Hardness	-0.896			
	0.000			
Height	0.877	-0.635		
	0.000	0.011		
Weight	-0.998	0.871	-0.893	
	0.000	0.000	0.000	
Specific loaf vol	0.924	-0.661	0.931	-0.944
	0.000	0.007	0.000	0.000

17. WHITE FIBRE REPLCEMENT

	Volume	Hardness	Height	Weight
Hardness	-0.779			
	0.001			
Height	0.960	-0.684		
	0.000	0.005		
Weight	-0.987	0.850	-0.940	
	0.000	0.000	0.000	
Specific loaf vol	0.994	-0.769	0.964	-0.989
	0.000	0.001	0.000	0.000

18. WHITE FIBRE ADDITION

	Volume	Hardness	Height	Weight
Hardness	-0.934			
	0.000			
Height	0.822	-0.901		
	0.000	0.000		
Weight	-0.925	0.981	-0.894	
	0.000	0.000	0.000	
Specific loaf vol	0.924	-0.987	0.893	-0.998
	0.000	0.000	0.000	0.000

P-Value < 0.05

Figure 5.1A – 6A : Digestibility of bread containing starch, flour and fibre replacement and addition, against control

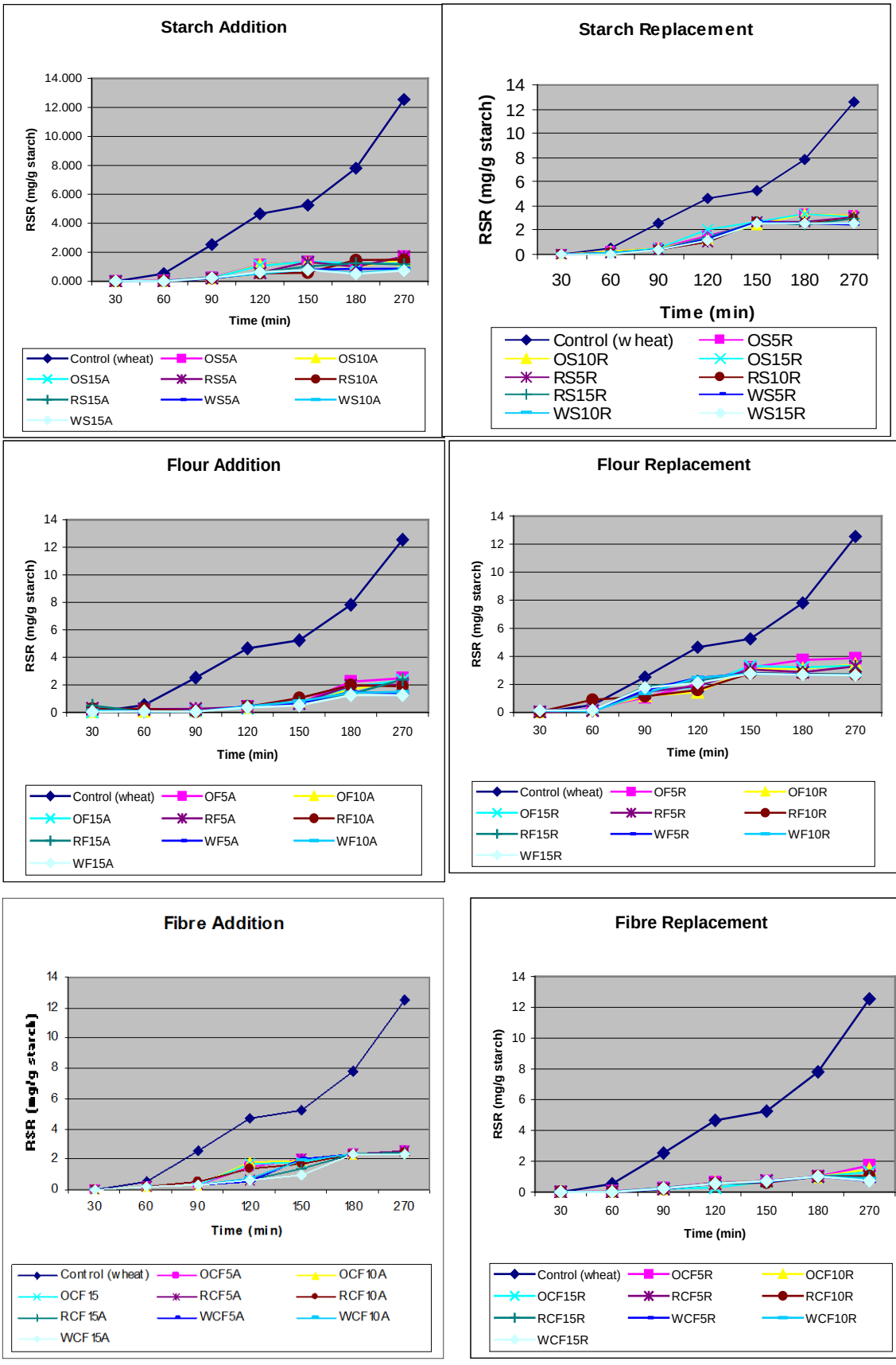
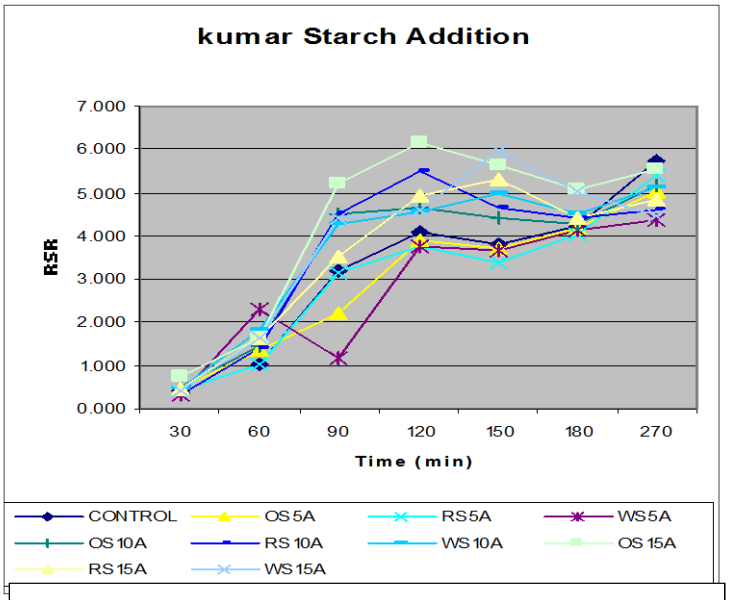
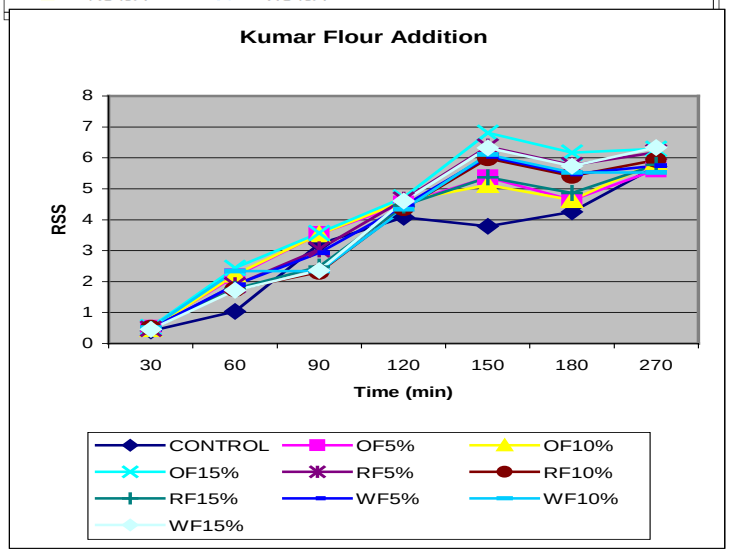
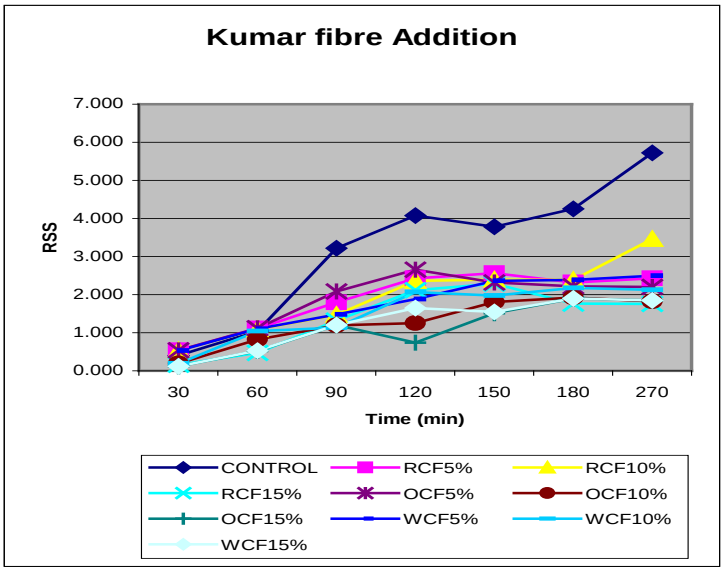


Figure 5.1B – 3B: Digestibility of bread containing starch, flour and flour addition







6.0 Overall Discussions

6.1 Proximate analysis of bread samples

A general trend showed moisture and protein content decreased as bread containing sweet-potato starch, flour and fibre concentration increased (Table 5.1-4.3 and Figure 5.1- 5.3).

Bread containing red, orange and white starch as replacement at 15% concentration level did not affect significantly the moisture content of control bread, while bread with red, orange and white addition starch did affected the moisture content differently at 15% level (Table 5.1).

In flour bread, the addition of orange and white flour at 15% replacement level did not affect the moisture level relative to the control bread of the normal control bread (Table 5.2 and Figure 5.2), whereas the addition flour the moisture content was affected significantly at 5-10%.

In fibre breads, the addition of fibre showed large effect on the moisture content of bread with red, orange and white in both replacement and addition mode. In all cases, both replacement and addition of fibre in breads causes changes to the overall moisture absorption behaviour by decreasing the moisture level, as level increased.

Among the bread samples, the moisture content of starch bread remained noticeably higher than that of wheat flour. The trends of decreased moisture

content hold true with increased addition of sweet potato concentration (Juarez-Garcia *et al.*, 2006). These results are in good agreement with studies conducted by Greene and Bovel-Brenjamin (2004). Juarez-Garcia *et al.* (2006) reported similar effects when using replacement wheat with increase amount of banana flour associated with rise of water absorption level, might be related to the protein and starch composition and low lipid level (Asp & Bjorck, 1992). This decrease is in relation to the competition for moisture, as fibre (Mcwillams, 2001) and starch molecules retain water when baking dough and limits the available water required for gelatinisation (Bennion & Scheule, 2000:). The same effect is suggested by Toufeili *et al.* (1999) in an investigation on the impact of cross-linked barley starch. A similar effect was noticed by Brennan and Samyue (2004) when using 5-10% dietary fibres on cereal based food products.

Table 5.1 and Figure 5.1 show protein content of replacement and addition starch breads were reduced when the concentration level increases. Bread containing red, orange and white starch with replacement at higher level does reduce the protein level significantly than starch with addition mode (Table 5.1). Similarly bread containing red, orange and white flour with replacement at higher level had protein content reduced greatly than with addition mode (Table 5.2)

From our result, we can see clearly that protein content of different types and concentration of sweet potato ingredients displayed more dependency on normal wheat flour. Protein content, relative to control bread was changed (from 8.95%) as the concentration level increases for starch, flour and fibre.

As expected, the bread with highest percentage of wheat flour (control) had the highest protein content. In relation to other work, most cereal flour contains less than 9% protein and most of the other major components of bread are also relatively low in protein (Table C.1-C.2, Appendix C, page 164-165). In fact, protein content in wheat is higher than that in sweet potato.

Greene and Bovel-Brenjamin, (2004) reported highest 7.7 and 7.5% protein contents found in bread supplemented with 50% and 65% sp flour, respectively. In all cases, there were no significant variations in cultivars or concentration types in protein levels found in test breads.

6.2 Physical properties of breads

Bread containing red, orange and white starch with both replacement and addition affected significantly the physical properties of normal control bread (Table 5.1 and Figure 5.1). From Table 5.1, the 15% orange and white replacement and 15% red, orange and white starch addition, induced a strong alteration on the dough structure, and hence significantly affected the loaf weight and volume. In all cases, 15% level addition starch had resulted in undesirable loaf weight, which indicated that high percentage starch might have promoted a physical interference to the gluten matrix that affected the loaf by decreasing the loaf weight and volume.

Bread containing red, orange and white with replacement and addition flour (Figure 5.2 and Table 5.2, respectively) produced almost same effect on the

loaf weight at 5-15%. The replacement and addition flour breads at 15% level exhibited the maximum loaf weight ranging from 78.13 g to 79.36 g compared to control bread (75.8g), indicate dense loaves present in red, orange and white flour. In fact the breads with residue fibre at 10 up to 15% were observed to have very dense loaves, resulting in high loaf weight (Table 5.3 and Figure 5.3). A similar increase in values of loaf weight was observed by Sharma and Chauhan (2000) in fenugreek flour supplemented breads, which significantly affecting the bread-making potential of fenugreek flour. A general trend showed that addition of red, orange and white replacement and addition bread increased loaf weight as the level of concentration increases, resulting in increase density and hardness, probably due to the highly rich fibre present of sweet-potato flour or might be due to ratio of low retrogradation amylose (Asp& Bjorck,1992) and high amylopectin (Touseili *et al*., 1999).

Bread containing red, orange and white with replacement and addition starch showed that loaf volume was affected differently (Figure 5.7), with a greater decrease at higher level observed in white starch replacement. Similar effect was presented in Figure 5.8 and Figure 5.9, respectively, where bread containing red, white and orange flour and fibre with replacement and addition decreased in loaf volume with increased flour or fibre concentration levels. This decrease might be due to dilution effect on gluten content with the addition of non-wheat flour to wheat flour has been reported to be associated with loaf volume depression effect of composite flours (Chavan and Kadam,1993; Dhingra and Jood, 2001).

Indeed low loaf volumes were expected because sweet potato is soft with low gluten content and rich in fibre and thus, the loaf reflect the gluten content of the bread (Greene and Bovel-Brenjamin, 2004). Bread made from soft flours usually yield low loaf volume (Yamauchi and others, 2001). Although the loaf volume decreased with the increased sweet-potato concentration, Tsou *et al.* (1989) cited that up to 15% of sweet-potato flour could be included in bread formulation without altering the sensory acceptance of the blended bread. Further studies have shown that the presence of protein-fibre from ingredients hinders the formation of the starch network that normally occurs either by granule-granule interactions or by amylose chain entanglements (Vosloo & Davel,1991; Asp & Bjorck, 1992), and hence affect the loaf volume.

Literature stated that the presence of fibre weakened the starch network, so that protein entrapped the gelatinised starch granules in a protein network, (Champpenois *et al*., 1998; Brennan and Samyue 2004). This is possibly related to the effect of 15% replacement method for sweet-potato fibre showing a slight increase in loaf weight, formed by mainly gluten and not by the highly amylopectin molecules (Asp& Bjorck,1992). However, large increase in loaf volume was in starch and flour at 5% and slowly reduces as the concentration levels increase, This could be due to retrogradation of amylose leaching (Touseili *et al*., 1999). The other reason could be the presence of relatively high concentration of low molecular weight thiols, especially reduced glutathione which activates proteolytic enzymes thereby causing detrimental effect on loaf volume (Indrani and Rao, 1992).

Breads containing red, orange and white starch with addition starch (up to 15%) had negative effect on specific loaf volume (density), compared to replacement starch breads. Data reported in Table 5.1- 5.3 indicated that while red, orange and white starch at 15% with both replacement and addition bread present lower specific loaf volume (compare against control), higher specific volume was reported for addition level at 5%. Comparable results have been obtained with formulation containing 15% red and white starch replacement and orange flour replacement (Table 5.1 – 5.2).

A trend showed specific loaf volume decrease as bread containing red, orange and white starch, flour and fibre concentration increases (Table 5.1-5.3 and Figure 5. 1-5.3). This decrease in specific loaf volume from 5 to15% bread containing starch replacement and addition, may be due to starch decreases the protein and thus decreases the particle rigidity of the swollen starch granules (Sharma and Chauhan, 2000). However, contradictory effects of gluten addition have been reported that the protein in wheat combined together with starch form starch-protein matrix is believed to be responsible for increased in specific loaf volume dough. In a related study, Singh *et al.* (2003), observed an increase in specific loaf volume of 9.8% by highly cross-linked waxy maize starch.

From our experiments, we can see clearly the effect of starch replacement and addition on bread quality, which related to the viscoelastic properties of sweet-potato starch blended with normal wheat starch. The properties of sweet potato starch-wheat flour, particularly their starch pasting parameters

have been investigated and results are found in Chapter Three. The RVA examination of their starch–water paste indicated that the paste viscosities obtained with three sweet potato starches were almost similar but lower than those of wheat starch (Table 3.1). The pasting properties (Table 3. 1- 3.4) relate to the fact that different types and concentrations of sweet potato display a behaviour response of rigid gel (Jangchud *et al.*, 2002., Wiesenborn *et al*., 1994).

Figure 5.1 indicated that starch requiring up to 10% level bread fades rapidly under normal bread-baking conditions. Such decline has been attributed to starch retrogradation (Rasper 1969; Asp & Bjorck, 1992). High degree of retrogradation in sweet potato–wheat starch combinations was observed at 15% levels of addition and replacement, where bread loaf volume and height were affected significantly. ($p<0.05$). High degree of retrogradation was also noted by Rasper (1969) and Rosenthal *et al* (1972).

From Figure 5.18, we can see clearly the effect of residue-fibre on the textural properties of normal wheat starch. Their effect was mainly attributed to changes in the water-binding capacity of the dough. Fibre retains moisture when cooking or baking cereal products and limits the available water required for the gelatinisation (Vosloo, 2005). Moisture content increased significantly ($p<0.05$) with increase in the level of sweet-potato fibre (5-15%) in wheat bread, for both methods. Similar results were also reported by Sharma and Chauban (2000) in fenugreek supplemented breads.

From Figure 5.17, sweet-potato bread hardness at 5-10% flour was comparable with that of wheat bread control, but decrease in sweet potato flour (replacement) was relatively small. Hardness of sweet-potato fibre bread (all levels) remained noticeably higher than that of wheat bread. The trends of decreased hardness hold true with increased addition of sweet potato (Shih *et al.*, 2005).

The hardness measured by Texture Analyser revealed a decrease in hardness values, with increasing sweet potato flour and starch, mainly observed in red and white varieties. This decrease in hardness of bread by incorporation of sweet potato could be due to the decreased water absorption and prevention of movement of moisture from starch to gluten by diffusion (Sidhu and Bawa, 2004, Calderon-Dominguez *et al.,* 2005). This is in contrast to the result obtained for orange variety, in which hardness increased with dense texture. Indeed the bread with high moisture content has soft texture than with bread low moisture level. In a general trend, loaf hardness was negatively effect of water content on sweet potato starch at up to 15% integration of test breads, as compared to that of the normal wheat bread, was small and insignificant.

6.3 Starch Digestibility

The effect of starch in sweet-potato bread digestibility in this experiment was studied and summarised in Figure 5.2A, 5.4A, 5.6A and 5.1B-3B. Sweet-potato breads (with addition levels), exert a greater effect on the rate and

extent of starch digestibility compared to that of Sweet-potato breads (with replacement levels), which yielded a low starch digestibility rate. Such an effect in starch breads (addition) suggests that the rate and extent of starch digestibility attributed to its starch content and composition of amylose. The findings in relation to the study conform to the findings with other studies on cereal based food products (Tsou *et al*., 1989; Toufeili *et al.*,1991; Asp & Bjorck, 1992)

The rate and extent of starch degradation is related to the reducing sugar release during digestion and hence the glycaemic response of an individual (Brennan and Samyue, 2004). Furthermore, Brennan and Samuye (2004) studied the starch in cereal based food products concluding that starch is entrapped within a food matrix comprising fully and partially gelatinised starch granules in a protein matrix. Such as, wheat strand is a large fraction of the starch, encapsulated in a protein matrix (Jenkins, Thorne & Wolever , 1987), during cooking or baking, the proteins coagulate to form a continuous network around each starch granule (Asp & Bjorck , 1985). Thorne *et al* (1983) and Brennan (2004) suggested that the interaction between starch and protein in food matrix influence the digestibility and glycaemic index response to starch.

Further research by Rincón *et al*., (2004) illustrated that bread made from high amylose wheat decreases starch digestibility, and hence reduces the glucose response. Due to the linear structure of amylose (Asp & Bjorck, 1992), starch granules rich in amylose are thought to have more extensive hydrogen bonding and, hence, more crystallinity in their structure than starch granules

with less amylose content. Consequently, they do not swell or gelatinize as readily upon cooking and therefore are digested more slowly, resulting in lower glucose responses than those with low amylose content. Hence, the structure and composition of starch, possibly due to the α-glucan in starch (Charlyn Vosloo, 2005) has a marked affect on the digestibility of the starch. As such Figure 5.21 illustrated that the low starch digestibility of wheat-control bread can be attributed to its high amylose (27%) content.

Interestingly, the low starch digestibility of wheat-control can also be related to its protein (12%) content (in Figure C.1, Appendix C, page 165). Among the bread tested, wheat bread was found to have the highest protein (11.8%) content (Table 5.3). The protein contents of the other bread tested were 7.3% for sweet-potato (starch) bread and 7.86% for sweet-potato (flour) bread. Removal of wheat at various levels and substituting with sweet-potato starches have similar effects in affecting the release of glucose. In consequence, starch digestion rate and therefore starch degradation is slower after in vitro digestion of bread. The reducing release sugar response value of sweet-potato breads compared to the normal wheat control is significantly greater as expected from a straight replacement factor. This holds true for the curves of reducing release sugar response for sweet potato bread demonstrated in Figure 5.5A. From this test is clearly seen that protein may have an influence in altering the rate and extent of starch degradation. This is apparently similar to a previous study (Dibildose & Malpica *et al*., 1985) that the removal of gluten from wheat resulted in an increased rate of amylose digestion *in vitro* and an enhanced low glycaemic index response, which has

indicated a general decline in sugar release with the presence of gluten in wheat. As such the results suggested that a negative relationship may exists between the protein content of food and its glycaemic response of wheat.

C. S. Brennan (2005) cited work done by others that effect of starch on starch digestibility and hence sugar release from foods varied may be delayed due to dietary fibres contributing to low starch digestibility of a sweet potato bread diet and possibly increasing digesta viscosity (Thompson and Yoon, 1984; Wong *et al*.,1985; Tsou *et al*.,1989; Brennan and Samyue,2004).

Figure 4.6A illustrates the rate of reducing sugar release during in vitro digestion influence by residue fibre. Inclusion of sweet-potato residue fibre significantly reduced the extent and rate of sugar release during digestion. Findings in relation to this study conform to the finding done in other studies. Addition of fibre significantly reduced the extent and rate of sugar release during digestion as comparison with starch and flour addition. Figure 5.2A and Figure 5.1B - 5.3B illustrate that the inclusion of starch, flour and residue fibre have similar effects in affecting the release of reducing sugar, and hence the degradation of starch from bread. Thus, the decrease in reducing sugar release (compared against the control) is greater than that of replacement factor. As such this clearly illustrates the role some forms of fibre have in inhibiting starch degradation. The rate of sugar release observed during the digestion of bread with added fibre could be explained by the fact that the sweet-potato starch.

The results of the test conducted using replacement of sweet-potato as shown in Figure 5.20, gave the same results as test conducted on addition method, which showed slower starch digestion rate, resulting in large amount of starch remain undigested. This undigested amount is so large, since we expected a higher curve of releasing sugar responses for addition levels, because research shown that cooked sweet-potato has a lot of digestible polysaccharides (Brand *et al.,* 1996, Nishimune *et al.,* 1991). The same effect was suggested by Toufeili *et al* (1991) in an investigation on the impact of cross-linked barley starch. Figure 5.1B - 5.3B showed the results of the test repeated for addition mode with sweet-potato starch alone, which illustrated a significant improvement on starch digestibility rate with 100% wheat flour. As such Figure 5.1B – 5.3B demonstrated good predicted curves for the different sweet-potato breads of addition mode. This observation truth is related to the work done by Tsou *et al* (1989) that in vitro starch digestibility of sweet potato starch, is the only about 20% hydrolysis, which can improved to 50% hydrolysis through secondary processing factor. These results suggest that sweet-potato bread, adopting replacement mode, is less digestible than wheat starch or sweet-potato bread, adopting addition mode, and as not as poor as fibre inclusions.

7.0 Conclusions and Recommendations

7.1 Conclusions

Different sweet-potato types and concentrations combined with wheat flour affected the physical properties and chemical composition (e.g., protein and moisture content). The differences between the physical properties were detected at 5, 10 and 15% concentration levels. Bread containing red, orange and white with addition starch tested have low protein content and high moisture content at 15% level. Bread containing red, orange and white replacement and addition starches showed reduction in loaf volume and increased loaf weight, due to their effect on water-binding capacity of dough. Red and orange addition starch increased the hardness of bread greater than those with replacement starch. Hardness of bread increased at 10% level for starches, whereas the hardness is great at 15% level in flour breads. Red, orange and white replacements and addition sweet potato fibre at 10 -15% had negative effect on bread height, volume weight and texture.

Attempt to substitute wheat flour by sweet potato starch and flour (both replacement and addition) at higher per cent level in bread to give a satisfactory product, have found to be successful in bread containing red and white replacement starches and orange replacement flour, which could be used to substitute wheat flour at 15%, without affecting the quality of the bread (combination of texture and bread size), than compared to the other breads.

However, starch has a peculiar attribute of reducing viscosity paste, which affects the use of starch at higher levels to produce desirable forms of bread products. Nevertheless, more work needs to be carried out in order to actually confirm the potential uses of the sweet potato flour particularly in areas such as bread and biscuit manufacture using composite flour formulation.

7.2 Recommendations for future work

The study with wheat flour blended with different types and concentrations of sweet potato, including technical and scientific literatures cited, concludes that in general up to 10% of non-wheat material (exception with crude fibre) may be used to obtained a desirable rheological quality of dough and loaf characteristics, however, we envisage that further work on sweet potato starch and flour needs to be investigated on the effect of starch binder which must be incorporated to maintain loaf volume. For instance, calcium alginate and gum acacia can be used up to 0.3% levels to monitor rheological, gas formation, gas retention and bread firmness properties of the sweet-potato starch-wheat starch and the best instruments to use would be Farinograph, Viscoamlygraph, Rheofermentormeter, test baking and TXT-texturometer.

Continuous assessment of the function of components in composite doughs, particularly non-wheat flour, other than starch may be more significant than the starch themselves. The rheological quality of bread doughs and loaf volume of the final product obtained at 15% using red and white replacement starches and orange replacement flour appears to be better, than those

obtained from starch themselves, which on its own, could gave rise to a less desirable product. Ideally, non-starchy polysaccharides components found with sweet potato might indeed contribute to the more favourable rheological characteristics. Their presence may cause changes in the water-binding capacity of the dough, though there is an indication that another mechanism, as yet unidentified, was operating which gave rise to the pronounced effect on of the rheological and bread quality upon addition of sweet-potato starch or flour at 5%.

Further to analysing the function of components of composite dough material by instruments and baking means, the investigation can be widened into mechanical dough development instead of traditional batch-type fermentation approaches, which possibly, could lead to use of higher levels of sweet potato in composite flour. The mechanical dough development employed must be follow systematically with a set of a correlative-integrated pattern. Using the following quality profile; starch/ sugar ratio, lipids, maillard browning and enzymic browning, and using their fundamental analysis of stress/strain and visco-elastic behaviour, etc , we shall characterise the texture of dough from different ingredients and built it into a quality control routine for different process.

8.0 References

Asp, N-Gl. 1995. Classification and methodology of food carbohydrates as related to nutritional effects. *American Journal of Clinical Nutrition* 61(Suppl):930-937.

Asp, N-G & Björck, I. (1992). Resistant starch. *Trends in Food Science and Technology* 3(3):111-114.

Bennion, M & Scheule, B. (2000). *Introductory foods*. 11th Edition. New York. Prentice-Hall. Pg:256

Brand-Miller, J, Foster-Powell, K & Colagiuri, S. 1996. *The GI factor: The glycaemic index solution*. Rydelmere. Hodder & Stoughton, pg: 32

Brennan, Charles S, (2005). Dietary fibre, glycaemic response, and diabetes. Molecular Nutrition. Food Resources. **49**, 560 – 570

Brennan, C.S & Samyue, E. (2004). Evaluation of starch degradation and textural characteristics of Dietary fibre-enriched biscuits. *International Journal of Food Properties*, 7(**3**): 647-757

Champenois, Yanns, Rao MA and Walker, Larry P, 1998. Influence of gluten on the viscoelastic properties of starch pastes and gels. *Journal of science Food and Agriculture*, **78**, pp119-126

Chavan, J.K., Kadam, S.S. (1993), "Nutritional enrichment of barley products by supplementation with non wheat flours", *CRC Crit. Rev. Food. Scieince Nutrition,* 33 pp.180-220.

Coursey, D.G., Ferber, C.E.M., (1979). The processing of yams. Plucknett L.D (Editor). Small-scale processing and storage of tropical root crops westview Press, Colorado, pp 189-211

Dhingra, S., Jood, S. (2001), "Organoleptic and nutritional evaluation of wheat breads supplemented with soybean and barley flour", *Food Chemistry,*. ***77*** pp.479-88.

Dibildose M, Malpica S, Urike M, et al. (1985). Beneficial effect of vegetable protein diet supplemented with *Psyllium plantago* in patients with hepatic encephalopathy and diabetes mellitus gastroenterology; *Food Chemistry* **8**: 901.

George Calderon-Dominguez, Reynold Farrera-Rebollo, Ramon Arana-Errasquin & Rosalva Mora-Escobedo, (2005). The effect of varying the mixing formula on the quality of a yeast sweet bread and also on the process conditions, as studied by surface response methodology. *International Journal of Food Science and Technology***, 40:** pp157-164

Greene, J.L., Bovell-Benjamin, A.C. (2004). Macroscopic and sensory evaluation of bread supplemented with sweet potato flour, *Journal of food science,* **69** (4):167173

Indrani, D., Rao, V.G. (1992), "Effect of processing methods on quality of whole wheat flour bread", *J. Food. Sci. Technol.*, **29** pp.293-5

Jenkins DJA, Thorne MJ, Wolever TMS, et al, (1987). The effect of starch protein interaction in wheat on the glycemic response and the rate of in vitro digestion. The American Journal of Clinical Nutrition, **45**, pg-946.

Juarez-Garcia,E. , Agama-Acevedo, E. , Sáyago-Ayerdi, S.G. , Rodríguez-Ambriz, S.L. And Bello-Pérez, L.A. (2006). Composition, digestibility and application in breadmaking of banana flour*. Plant Foods for Human Nutrition* **61**: 131-137

McWilliams, M. 2001. *Foods. Experimental perspectives.* 4th Edition. Upper Saddle River, New Jersey. Prentice-Hall. pg-193

Nishimune, T, Yakushiji, T, Sumimoto, T, Taguchi, S, Konishi, Y, Nakahara, S, Ichikawa, T & Kunita, N. (1991). Glycemic response and fiber content of some foods. *American Journal of Clinical Nutrition,* **54**(2):414-419

Rasper, V 1969. Investigations on starches from major starch crops grown in Ghana:. Particle size and particle size distribution Part II: *Journal Science Food Agriculture*, **20**, 642

Raŝper, V (2006) Investigations on starches from major starch crops grown in Ghana I. - Hot paste viscosity and gel-forming power *Journal Science Food Agriculture*, 20 (3) , pp 165 – 171

Rincon, Alicia Mariela., Padilla, Fanny C, (2004). Physicochemical properties of breadfruit (Artocarpus Altilis) starch from Margarita Island, VenezuelaArchivos *Latinoamericanos de Nutrición. ALAN v.54 n.4 Caracas dic.* ISSN 0004-0622 *versión impresa.*

Rosenthal, FRT.,Pelegrino, S.L and Correa, A.M.N (1972). Study on the starch of Dioscorea, Dioscorea alata (edible), and and Dioscorea cinnamofolia (non-ebible*). Starch Starck* **24**:54

Sharma, H.R., Chauhan, G.S. (2005), "Physical, sensory and chemical characteristics of wheat breads supplemented with fenugreek", *Journal of. Food Science and Techology,* **35** (4) pp. 229-242

Shiraishi, K., Lauzon, R.,Yamazaki, M., Sawayama, N (1995). Rheological properties of cocoyam starch paste and gel, *Food Hydrocolloids*, **9** (2): 69-75

Sidhu, Jai Pal, and Bawa, (2004). Effect Acacia Incorporation on the bread making performance of Punjab wheat. *International Journal of Food Properties* **7** (2) pp-175-183.

Tsou, Samson C.S., Kan, Kuang_Kung.,Wang, Shu_Jen (1989). Biochemical studies of sweetpotato for better utilisation at AVRDA. Mackay, Kenneth., Palomar, Manual., Sanico, Rolinda (editors). *Sweet potato research and development for small farmers*, SEAMEO-SEARCA, Philippines, pp 213-225

Thorne, Mary Jane., Thompson, Lilian U and Jenkins, David J. A, (1983). Factors affecting starch digestibility and the glycaemia response with special reference to legumes. *The American Journal of clinical nutrition* **38**, pp 481-488

Toufeili, I, Habbal, Y, Shadarevian, S & Olabi, A. (1999). Substitution of wheat starch with non-wheat starches and cross-linked waxy barley starch affects sensory properties and staling of Arabic bread. *Journal of the Science of Food and Agriculture* **79**(13):1855-186

Yamauchi ZN, Kanenori T, Yuji O, Kazufumi Y, Nanako I, Hideho M (2001). The breadmaking quality of a domestic flour blended with an extra strong flour, an staling of the bread made from the blended flour. *Food Science and Technology Resource* **7**(2):120–5.

Yoon JH, Thompson LU, Jenkins, DJA (1983). The effect of phytic acid on in vitro rate of starch digestability and blood glucose response. *The American Journal of Clinical Nutrition*; **38**: 835

Vosloo, Mc & Davel, Ei (1991).The effect of final temperature on the α-amylase activity, consistency and firmness of egg-starch pastes.] *Journal of Dietetics and Home Economics* 19(3):82-86.

Vodoo, M. Charlyn, (2005). Some factors affecting the digestibility of glycaemia carbohydrate and blood glucose response, Journal of *Family Ecology and Consumer Science* **33**, pp1-9

Wiesenborn, D.P., Orr, P.H., Casper, H.H. and Tacke, B.K., 1994. Potato starch paste behaviour as related to some physical/chemical properties. *Journal of Food Science* **59**, pp. 644–648

Wong, R.B.K. and Lelievre, J., 1981. Viscoelastic behaviour of wheat starch pastes. *Rheol Acta* **20**, pp. 299–307

Appendix A

Table A.1: Some important physicochemical properties of amylose and amylopectin

Properties	**Amylose**	**Amylopectin**
Molecular structure	Linear (α-1,4)	Branched (α-1,4; α-1,6
Molecular weight	~ 10^5 Daltons	~10^2 Daltons
Degree of polymerization	1500-6000	$3x10^3$-$3x10^5$
Helical complex	Strong	Weak
Iodine colour	Blue	Red-purple
Dilute solutions	Unstable	Stable
Retrogadation	Rapidly	Slowly
Gel property	Stiff, irreversible	Soft, reversible
Film property	Strong	Weak brittle

(**Source**: Chen, 2003)

Table A.2: Food ranking according to glycaemic index (**Source**: Brennan. 2005)

Food product	Glycaemic index (glucose =100%)	Glycaemic load (per serving)
Rice (jasmine)	109	46
White bread	95	15
Lucozade	95	40
Cornflakes	92	24
Rice krispies	82	21
Gluten-free bread	79	10
White bread (with resistant starch fibre white)	77	11
Doughnut	76	17
Rice (long-grain, quick cook)	72	20
Weet-bix	69	12
Rice (boiled, white)	69	30
Fanta	68	23
Rice (Basmati)	58	22
Milo	55	9
Kiwi fruit	53	7
Coca cola	53	14
Banana	53	13
Orange juice	50	13
Ice cream	50	6
Baked beans	48	7
Sponge cake	46	17
Oat bran bread	44	8
Muffin	44	13
Barley bread	43	9
Porridge (oats)	42	9
Rye bread	41	5
Apple juice	40	12
Rice (high amylose)	37	15
Yoghurt	34	5
Chickpea	33	10
Lentils	30	5
Apple	30	4
All-bran	30	4
Kidney beans	29	8

Adapted from Foster-Powell *et al*. (2002)

Appendix B

Table B.1: Chemical characteristics from starch obtained from various sources

Starch	Amylose (%)	Lipids (%)	Protein (%)	Phosphate (%)
Corn	28	0.8	0.35	0.00
Waxy corn	<2	0.2	0.25	0.00
High-amylose-corn	50-70	Nd	0.5	0.00
Wheat	28	0.9	0.4	0.00
Potato	21	0.1	0.1	0.00
Tapioca	17	0.1	0.1	0.00
Mung bean	39	0.3	0.3	nd

(**Source**: Coursey *et al*., 1979)

Appendix C

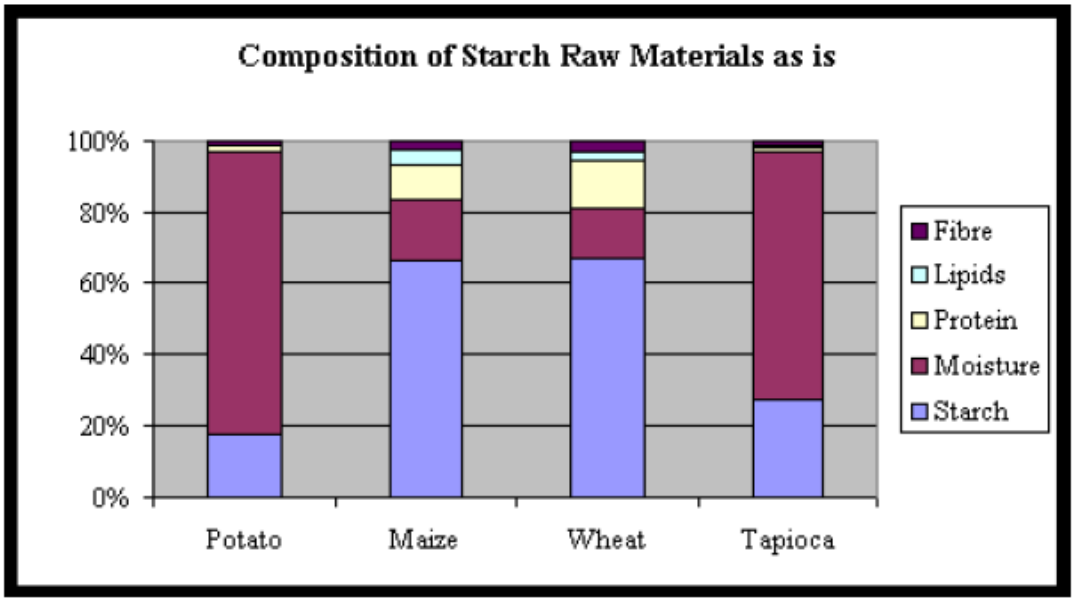


Figure C.1: Composition of starch raw materials (International starch Institute, 1999)

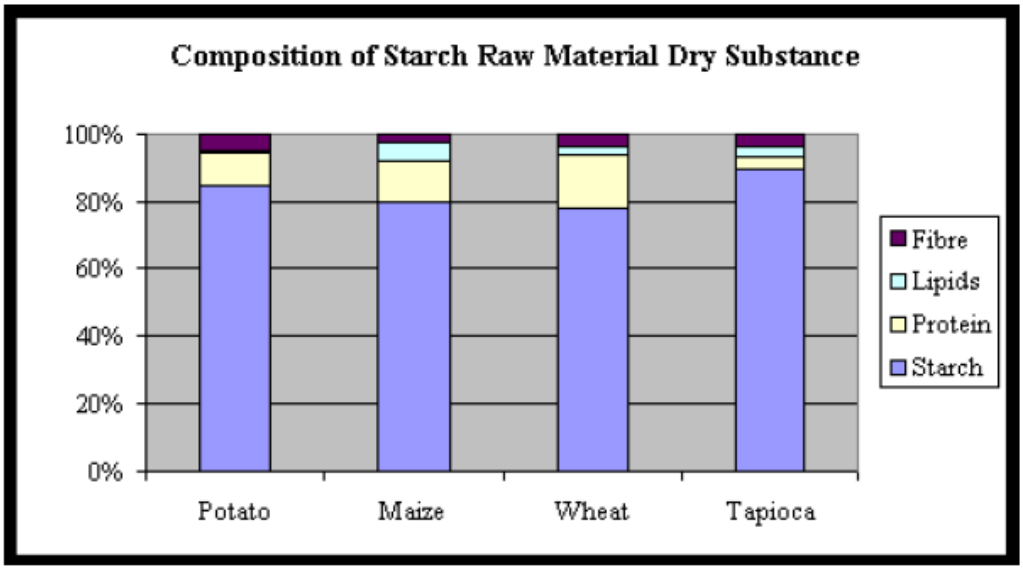


Figure C.2: Composition of starch raw materials dry substance (International starch Institute, 1999)

Table C.1: USA Sweet potato Bread composition

Measure Description	**100 Grams**	**1 slice**
Servings	**1**	**1**
Servings Weight	**100g**	**25g**
Water (g)	33	8.25
Energy (kcal)	288	72
Protein (g)	7.87	1.97
Fat, total (g)	6.1	1.52
Carbohydrate (g)	49.93	12.48
Sugars, total (g)	7.38	1.84
Fiber, total dietary (g)	2.1	0.5
Alcohol (g)	0	0
Cholesterol (mg)	54	14
Saturated fatty acids, total (g)	1.28	0.32

Source: The USDA online database on food composition. 60-nutrient profiles of more than 13,000 foods, albeit USA. http://www.ars.usda.gov/Services/docs.htm?docid=7783