CONTRIBUTION OF SELECTED INGREDIENTS TO THE QUALITY OF WHEAT/UNPEELED ORANGE FLESHED SWEET POTATO PUREE COMPOSITE BREAD

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A DISSERTATION SUBMITTED TO DIRECTORATE OF RESEARCH AND GRADUATE TRAINING IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN FOOD TECHNOLOGY OF KYAMBOGO UNIVERSITY

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DECLARATION

I hereby declare that this study is an original work done by me. Contributions of other people, which were used in writing this book, are duly acknowledged and appreciated. The study, as designated in this dissertation, has never been submitted for award of any degree in any other institution of higher learning.

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APPROVAL

This is to certify that the work presented here in this dissertation is the student's original work, done by him under our supervision, and is now ready for submission for the award of the degree of Master of Science in Food Technology of Kyambogo University.

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DEDICATION

This book is dedicated to God, my Wife, Mrs. Doreen M. Shaka; my children, Valerian A. Shaka, Jayden M. Shaka and Gaelle A. C. Shaka and my entire family of Amb. Prof. and Mrs Arsene M. Balihuta (Dad, Mom, Lilian and Mark).

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LIST OF ABBREVIATION/ACRONYMS

AB	Alternaria Bligh
AACC	Association of American Cereal Chemistry
AML	Amylose
AMP	Amylopectin
ANOVA	Analysis of Variance
AOAC	Association of Official Analytical Chemists
CIP	International Potato Centre
DHAA	Dehydroascorbic acid
DOS	Degree of Softening
DWB	Dry Weight Basis
FAO	Food and Agriculture Organization
HTST	High Temperature Short Time
ICC,	International Association for Cereal Chemistry
NaCCRI	National Crops Resources Research Institute
NARO	National Agricultural Research Organization
NDP	National Development Plan
OFSP	Orange Fleshed Sweet Potato
PCA	Principle Component Analysis
RAE	Retinol Activity Equivalence
RDA	Recommended Dietary Allowance
RSM	Response Surface Methodology
SPVD	Sweet Potato Virus Disease
SPW	Sweet Potato Weevil
TCC,	Total Carotenoid Content
TPA	Texture Profile Analysis
UBOS	Uganda National Bureau of Statistics
UK	United Kingdom
UNICEF,	United Nation Children's Fund
VAD	Vitamin A Deficiency
WA	Water Absorption

ABSTRACT

The development of bread from composite formulations is increasing and has attracted much attention from researchers driven by the desire to find non-wheat-bread-making alternatives in order to reduce dependence on imported wheat. However, formulation and production of acceptable composite bread requires understanding the effects of ingredients on bread quality. This study aimed at assessing the contribution of selected ingredients to the quality of composite dough made from wheat flour and unpeeled orange-fleshed sweet potato (OFSP) puree as well as physical qualities, nutritional composition, and consumer acceptability of the resultant bread. A 2-level fractional factorial design (2^{8-3}) at resolution IV was used to design a screening experiment and Response Surface Methodology (RSM) was used to analyze data. Prmax and Water Absorption of the composite dough were studied using the alveoconsistograph. Physical properties and nutritional composition of composite bread were analyzed using AACC, AOAC and ICC standard methods. Consumer acceptability was assessed by an untrained panel of evaluators using a 9-point Hedonic scale. Significant models were developed at $p<0.05$ and coefficient of determination, R^2 was used to test fitness of the model terms. Prmax and Water Absorption decreased as proportions of unpeeled OFSP puree increased from 20% to 50%. Proportion of unpeeled OFSP puree negatively affected crumb colour, specific volume, springiness, flavour, aroma and general acceptability but had a positive effect on weight, moisture content, Total carotenoid content, β-carotene content, vitamin A content, reducing sugar content, protein content, Amylose and amylopectin ratio and starch content. Yeast positively affected volume and crust colour with negative effect on baking loss, staling rate, firmness and chewiness. Treatment of unpeeled OFSP (pasteurized and unpasteurized/fresh) negatively affected texture. Variety had a significant effect on crude fiber with NASPOT13O having a negative effect and NKB135 exhibiting a positive effect. Fat negatively affected cohesiveness. Ascorbic acid (improver) had the least effect on the study responses. Principal Component Analysis indicated a negative correlation between nutritional and sensory properties. A positive correlation between textural properties and sensory properties and a high correlation between physical and sensory properties of the bread were observed. The study concluded that the most significant among the selected ingredients that affected quality of wheat/unpeeled OFSP puree bread were proportion of puree, yeast and fat. The study also concluded that treatment and variety had significant effects on the quality of the composite bread.

CHAPTER ONE: INTRODUCTION

1.1 Background

Composite flours have generally been referred to as a combination of flours from other crops, starches and other ingredients whose intended purpose is to substitute partially or fully wheat flour in home or industrial bakery and pastry products (Shittu et al., 2007). According to Bugusu et al. (2001), composite flours are used to promote overall use of domestic agricultural production. The FAO supported this argument by reporting an increase in economic benefits of using composite flours in food products if imports of wheat were to be reduced or even eliminated and that demand for bread and pastry products could be met by using locally grown products as an alternative to wheat flour (Jisha et al., 2008).

Formulating composite products remains a complex task, especially due to the favorable characteristics of wheat flour for bread production (Ohimain, 2014). The distinctive ability of its inherent gluten protein to create intricate viscoelastic protein networks upon water addition contributes to its suitability. Research has however demonstrated that partial addition of non-wheat flours or complete replacement of wheat flour in bread can yield composite breads with similar quality characteristic to wheat flour bread. Oladunmoye et al. (2010),Mepba et al. (2007) and Lagassé et al. (2006) showed that replacing 10-20% of wheat flour with flours from cereals/grasses, tubers/root crops, legumes and fruit crops has manufactured bread of acceptable quality without substantial impact on colour, crumb structure, texture and shelf life. Odedeji & Adeleke (2010), and Schober et al. (2008) showed that addition of maize, rice, millet and other cereals, tubers and fruits generally improved the water binding capabilities, gas permeable structures of the composite bread. Dako et al. (2016) indicated that blending different proportions of OFSP flour and wheat flour in making of bread significantly improved loaf weight.

The advancement of technology to boost the quality of composite bread has prompted the exploration of various strategies. These approaches involve incorporating additives and enhancers like modified starches, hydrocolloids, gums, proteins, and enzymes into substituted wheat bread. Ortolan & Steel (2017) highlighted the utilisation of modified tuber starches in mitigating challenges linked to the reduction of native wheat flour starch during bread production, a phenomenon influenced by substitution levels and types.

Use of orange-fleshed sweet potatoes (OFSP) as a food-based approach has been suggested as an alternative option to combat vitamin A deficiency (VAD) in Uganda. The OFSP have high β-carotene and are seen as a cheaper and complementary source of vitamin A for the rural poor families who are the most vulnerable to VAD in Uganda. The opportunity is that about 90% of the rural poor households in Uganda use sweet potato as a staple or co-staple. However, OFSP are not accepted in most of the communities due to their sensory characteristics (Tumwegamire et al., 2007). In order to improve the uptake and utilization of the β-carotene rich OFSP, latest development in bread production have led to use of puree in as an ingredient to improve rheological and baking properties (Truong & Avula, 2010). Commercial production of OFSP puree bread is in practice across countries in sub-Saharan Africa, including Kenya and Rwanda (Bocher et al., 2017). Sweet potato puree enhances colour of the bread in which it used as an ingredient. However, the change in colour of peeled and cooked sweet potatoes may impact the final puree's appearance due to enzymatic reactions, a process that can be avoided by preparing puree without peeling the tubers. The viscoelastic properties and textural characteristics of restructured products derived from sweet potato puree were significantly enhanced by the gel structure of the potato puree, as highlighted in the study by Wang & Kays (2001). In the advancement of research, sweet potato peel powders have been optimized as ingredients in composite bread formulations to enhance quality characteristics of composite bread. However, Ade-Omowaye et al. (2017) evaluated the effect of OFSP peel powder on the physiochemical properties and sensory attributes of bread and reported an increase in the fiber and antioxidant content, but also a darker crust colour and lower overall acceptability. Sobukola et al. (2018) concluded that using OFSP peel flour as an ingredient increased the fiber and mineral content of the bread, but also resulted in lower loaf volume and increased loaf firmness.

Whereas the quality of composite bread has greatly been attributed to the degree of substitution of wheat flour with non-wheat flours, studies have also indicated the effect of bread making processes on the quality attributes of composite bread. Eke-Ejiofor & Onyeso, (2019) assessed the effect of different methods of processing OFSP (boiling, steaming, roasting, frying and microwaving) on the physiochemical properties and proximate composition of composite bread and concluded that whereas boiling made available more minerals in the composite bread, roasting and frying enhanced the availability of carbohydrates, total ash, fats and protein.

1.2 Problem statement

The majority of research studies have focused on examining how replacing wheat flour with various ratios of non-wheat flours impacts quality attributes of composite bread. Studies have also focused on optimization of bread improvers and baking processes to enhance quality of composite bread attributes. However, there is limited information on how the essential ingredients used in making bread contribute to the physical properties, nutritional composition and sensory characteristics of composite bread. Whereas, there is literature on how different heat treatment methods affect the quality of OFSP composite bread prepared from peeled sweet potatoes, there is inadequate information on the effects of pasteurization on the rheological properties of composite dough and quality characteristics of OFSP composite bread prepared from unpeeled sweet potato tubers. Worth still, there are hardly any studies on the effects of OFSP varieties grown in Uganda in regards to rheological properties of dough and quality attributes of composite OFSP puree bread. Therefore, this study sets out to investigate the effects of the unpeeled OFSP varieties and processing methods on the rheological properties of wheat/unpeeled OFSP puree dough and the subsequent effects of bread making ingredients, processing methods and OFSP varieties on the quality attributes of wheat flour/unpeeled OFSP puree composite bread.

1.3 Objectives

1.3.1 General objective

To assess the contribution of selected ingredients to the quality of wheat/unpeeled OFSP puree composite bread

1.3.2 Specific objectives

1. To determine the effect of unpeeled OFSP varieties (NASPOT 13O and NKB135), puree processing treatments (pasteurized and unpasteurized/fresh) and proportion substitution of wheat flour with unpeeled OFSP puree on the rheological properties of wheat/unpeeled OFSP puree composite dough.
2. To determine the effect of ingredients (OFSP varieties, puree, sugar, fat, salt, yeast and ascorbic acid), processing treatments (pasteurization and unpasteurized/fresh) and proportion substitution of wheat flour with unpeeled OFSP puree on the wheat/unpeeled OFSP composite bread physical and nutritional properties.
3. To determine the effect of baking ingredients, processing treatments, OFSP varieties and proportion substitution of wheat flour with unpeeled OFSP puree on consumer acceptability of the wheat/unpeeled sweet potato composite bread.

1.4 Hypotheses

1. There is no relationship between sweet potato varieties, sweet potato processing treatments, proportion replacement of wheat flour with OFSP and the rheological properties of composite dough.

2. There is no relationship between baking ingredients, OFSP varieties, processing treatments, proportion replacement of wheat flour with OFSP and physical or nutritional attributes of composite bread.
3. There is no relationship between baking ingredients, OFSP varieties, processing treatments, proportion replacement of wheat flour with unpeeled OFSP and the consumer acceptability of composite bread.

1.5 Justification of the study

The outcomes of this study will contribute to the understanding of the composite dough behavior and composite bread production, providing valuable insights for the food industry and researchers interested in developing functional bread products from locally grown crops. The findings will also inform the need to optimize formulation of ingredients and processing methods to facilitate production of composite bread with improved physiochemical properties, nutritional profiles and sensory attributes. Furthermore, exploitation of underutilized crops like sweet potato in bread production has a positive impact on reduction of wheat importation, agricultural sustainability, promote local crop diversity, and address food security challenges.

CHAPTER TWO: LITERATURE REVIEW

2.1 Sweet potato production

Sweet potatoes (*Ipomoea batatas* Lam) are edible underground tubers widely consumed in various regions globally because of their substantial harvest, nutritional benefits, and capacity to endure challenging environmental circumstances (Mohanraj & Sivasankar, 2014). Sweet potatoes are an important food crop in Uganda for both household income and food security (Gibson, 2013). As a source of calories, sweet potato contributes approximately 19-21% of the total energy requirement. Figure 2.1 shows global production of sweet potato (SP). Table 2.1 shows Uganda's estimated annual production, ranking it 7th largest producer in Africa and 10th globally after United States of America.

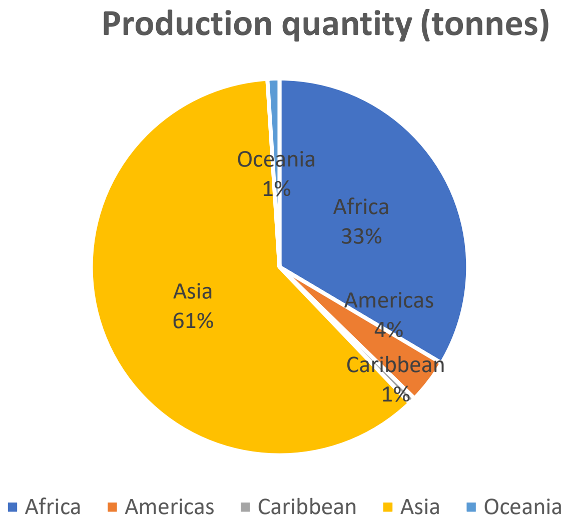

Figure 2. 1. Regional distribution of sweet potato production in the year 2021

Source: FAOSTAT (2021)

Table 2.1. Estimated annual production of sweet potato in major growing countries

Country	Production quantity (tonnes)	Area harvested (ha)
China, mainland	47,621,146.93	2,197,319
Malawi	7,449,971.81	314,356
Tanzania	4,991,861.06	680,327
Nigeria	3.943,045.69	1,510,408
Angola	1,788,342	187,924
Ethiopia	1,697,582.71	68,117
Indonesia	1,649,000	74,813
Rwanda	1,328,750	192,484
United States of America	1,308,728	61,796
Uganda	1,267,696.54	299,112
Viet Nam	1,231,469.21	98,193
Madagascar	1,143,320.1	137,430
India	1,121,000	106,000
Brazil	824,680	56,183
Kenya	777,140.64	61,796

Source: FAOSTAT (2021)

In Uganda, sweet potatoes rank as the fourth most significant crop in terms of production quantity, following maize, cassava, and bananas (UBOS, 2020) with a per capita consumption of 95kg according to FAO Statistics (2021). The major producing districts by region are Busoga (194,000 MT) with the highest sweet potato production, followed by North Buganda (187,000 MT). The sub-regions with the lowest annual production were Ankole (40,000 MT) and Tooro (39,000 MT). Acholi (12.2 MT/ha) and Lango (7.5 MT/ha) reported the highest annual yields. The lowest annual yields were in Busoga (3.7 MT/ha) and Elgon (3.4 MT/ha) (UBOS, 2020).

2.2 Sweet potatoes and their origin

Sweet potato (*Ipomoea batatas* Lam) was first cultivated in tropical America. It was introduced along the eastern and western coastlines of Africa before spreading to inland regions. Additionally, there was a later introduction of sweet potatoes from India to East Africa, facilitated by British colonial influences (Roullier et al., 2013).

There are three major classes of sweet potato grown in Uganda that is white, yellow and orange Flesh Sweet potato (OFSP) distributed across the six agro-ecological zones. The varieties can be differentiated by their skin and flesh colour.

In order to increase household and commercial production of sweet potatoes, Uganda government has increased concerted efforts to facilitate increased sweet potato breeding under National Agricultural Research Organization (NARO) in order to produce improved varieties that have end-user qualities. As many as 27 varieties of sweet potato have been developed under NARO (Ssemakula et al., 2014). The varieties have been developed to improve on attributes like resistance to sweet potato virus disease (SPVD), Sweet potato weevils (SPW), and Alternaria blight (AB), high dry matter content, good root shape, acceptable culinary qualities, balanced harvest indices, and/or enhanced β-carotene into a genetic background of high yield. Of the 27 varieties released, some have become very popular within and outside Uganda. Pale (white/yellow) fleshed cultivars such as Dimbuka, Sukai, Tanzania and Kawogo are the most (86%) produced. These are characterized by sweet taste, high dry matter content and being hardy with regard to harsh environmental conditions. Some varieties have high dry matter and are traditionally the most preferred types, while others have low dry matter and are less preferred (Mwanga & Ssemakula, 2011).

OFSP is not highly regarded due to purported inferior sweet taste, low dry matter content and perishability, although it is cultivated for its nutritional and monetary value (Nakanyike, 2014).

Outstanding sweet potato traditional varieties grown in Uganda include; cream white fleshed varieties (Tanzania, Tororo 3, New kawogo, kakamega, Ejumula); OFSP varieties (NASPOT 5,7,8, 9O, 10O,11, 12O, 13O) and NAROSPOT cream varieties (1, 2, 3,4 and 5). Phenolic compounds and carotenoids are responsible for distinguishing flesh and skin colours (deep yellow, red to orange, purple, and pale) of sweet potato along with antioxidant properties (Steed & Truong, 2008).

2.3 Bio fortification of sweet potato in Uganda

Biofortification is a “new strategy” that uses conventional breeding techniques and biotechnologies to reduce “anti-nutrients” or increase the micronutrient quantity of staple foods (SUD, 2018). This innovation is seen as a way of delivering “naturally” – vs processed – fortified foods to people living in rural areas with limited access to fortified foods, more readily available in urban areas. Conventional biofortification introduces a desired genetic characteristic through cross breeding of two vegetal varieties (e.g. orange-fleshed sweet potato results from the crossbreeding of a variety with high level of Vitamin A and local varieties). Frequent consumption of biofortified staple foods has the potential to bolster the body's micronutrient reserves and guard against deficiencies.

OFSP refers to numerous cultivars of sweet potato (*Ipomoea batatas*) that are high in beta-carotene, a precursor to vitamin A. The beta-carotene content is responsible for the tuber's distinctive orange colour

NASPOT 13O (as one of the varieties of interest in this study) is produced from combination of cultivar NASPOT 12O, with ‘NASPOT 7’. The variety was initially selected in 2006 as genotype number 292, given the UPVRC/ NARO serial number 13, and officially released as ‘NASPOT 13O (Mwanga et al., 2016).

NKB135 (another variety of study) is a biparental hybrid of ‘New Kawogo’ (NK- locally bio fortified variety released in 1995 with a red skin) and ‘Beauregard’ (B- a variety bio fortified in United States of America with a brown skin and deep orange flesh). The progeny was released in 2023 and given the UPVRC/NARO serial number NKB135 (Yada et al., 2017).

The variations in the biofortified varieties of OFSP is defined by the deepness of the orange colour for the flesh consequently variation in the β-carotene levels. That is to say: NATSPOT 7 and 8 are pale orange compared to NASPORT 9O and 10O which are dark orange hence high levels of β-carotene. Further comparison indicates however, that NASPOT 12O and 13O have a deeper orange flesh compared to NASPOT variety 10O thus having higher levels of β-carotene. As a result of the current agro-industrialization agenda in Uganda (NDP III), current research is focusing on sweet potato varieties with increased β-carotene levels, increased smoothness of the root skin (to allow industrial processes like effective washing, peeling) and low dry matter (to allow for preferred product qualities like pureeing, cooking). Thus, the development of an OFSP variety NKB135 that has a much deeper orange colour of the flesh than the latest varies of NATSPOT 12O and 13O (Yada et al., 2017).

2.4 Diversification in Sweet Potato puree utilization

Sweet potato puree has found application as an ingredient in a wide array of food items, ranging from baby foods and desserts like puddings, pies, and cakes, to staples such as bread and patties, as well as soups (Kudoh & Matsuda, 2000). Its most notable achievement on the commercial front has been in the realm of baby foods (Annette et al., 2023). Gladney (2005) introduced an innovative approach for enhancing the value of sweet potatoes through their transformation into products conventionally derived from fruits. This strategic insight was driven by the acknowledgment of the nutritional parallels between sweet potatoes and fruits. As a consequence, multiple patented techniques were developed, focusing on incorporating sweet potato purees into fruit and vegetable beverages within Japan and the United States. Moreover, reconfigured items crafted from sweet potato puree have been innovatively produced by integrating gelling agents like carboxymethyl cellulose, hydroxymethyl cellulose, and the alginate-calcium system. These products, simulated-baked sweet potatoes and restructured french fries have good sensory quality and textural properties (Tomlins et al., 2010).

Recent research conducted in Sub-Saharan African countries indicates that replacement of wheat flour with OFSP puree has yielded composite bread of acceptable quality, as opposed to the substitution with OFSP flour (Awuni et al., 2018). At the International Potato Center (CIP) in Rwanda, consumers responded positively to products manufactured from OFSP puree. The organization's efforts in diversification revealed an 18% rise in profit margins by transitioning puree production from peeled to unpeeled roots. This led to the development of a novel product, ‘high fiber' composite bread made from the puree, which garnered greater acceptance (Bocher et al., 2017). In Kenya, utilization of OFSP puree was transformed from a direct baking ingredient for the baking industry to a processed, packaged and readily available shelf-stable product on the market (Muoki & Agili, 2015; Stathers et al., 2013). It can be concluded that OFSP puree derived from Ugandan varieties employed in this study (among other varieties) could provide an opportunity to increase the recommended dietary intake of vitamin A (retinal) hence reducing VAD and livelihood through industrialization.

2.5 Post-harvest losses of sweet potatoes in Uganda

Although sweet potatoes are very important in Uganda, there are still high post-harvest (PH) losses as result of weevil infestation, rotting, thin delicate skin, respiratory losses and sprouting and most of these (up to 60%) occur at farmer level (Maziya-Dixon et al., 2017). Post-harvest losses vary between 15 and 65% during storage for one to four months (Ray & Tomlins, 2010). Losses during transportation and storage vary between 20-25%(Parmar et al., 2017), while market losses have been reported as one out of 10 bags from transportation to retail as a result of poor harvesting methods, handling, packaging and transportation.

Post-harvest losses are caused by high respiration rates, biochemical and compositional changes and physical damages (Adewumi et al., 2009). Diversification of sweet potato use is therefore required to reduce wastage and add value to the crop.

2.6. Prevalence of malnutrition in Uganda

Malnutrition is responsible for 60% of the 11 million fatalities among children under the age of four that occur worldwide each year (Sunguya et al., 2006). Malnutrition is defined as problems caused by an insufficient (under-nutrition) or excessive (over-nutrition) diet, or by an inability to absorb or assimilate dietary nutrients (UNICEF, 2008). It is one of the most critical health issues impacting newborns, children, and pregnant women.

Despite concerted endeavors to address malnutrition, statistics indicate that approximately 161 million children under the age of five worldwide suffer from chronic malnutrition (FAO, 2014). Moreover, 'hidden hunger,' characterized by a deficiency in essential micronutrients such as vitamin A, iodine, iron, and zinc, affects over 2 billion individuals globally (FAO, 2014).

As specified by the Institute of Medicine, recommended dietary allowance (RDA) for vitamin A varies depending on age and gender, with 700 mg/day for women and 900 mg/day for men in healthy adults (Pfeiffer et al., 2013). The RDA for children, pregnant women, and breastfeeding women ranges from 300 to 900 mg/day, 770 mg/day, and 1300 mg/day, respectively. To prevent emergence of symptoms related to vitamin A deficit among children aged 1 to 5 years, a minimal intake of approximately 200 mg/day is imperative (Miller et al., 2002; Strobel et al., 2007)

In Uganda, the prevalence of VAD is 8.3 and 9.0% in the urban and rural areas, respectively (UBOS, 2018). Higher prevalence rates have been reported in the following sub regions of Uganda: Acholi (15.4%), Busoga (12.8%), and West Nile (11.2%) (UBOS, 2018). High implementation costs of industrial food fortification and supplementation programs, and their limited reach in resource-poor rural communities, justify continued support of alternative food-based approaches such as diet diversification and the biofortification of daily staple crops, such as orange-fleshed sweet potatoes (OFSP), with vitamin A (Mayer et al., 2008). Innovative food-based approaches have included production of beta-carotene rich OFSP as a preventive and therapeutic nutrition-specific intervention targeting livelihoods that can also potentially prevent and mitigate vitamin A deficiency (Laurie et al., 2018).

2.7 Nutritional characteristics of OFSP

2.7.1 Nutrient importance of OFSP composite bread

OFSP ranks as number one among all vegetables in terms of diet and nutrition (Neela & Fanta, 2019), and has been reported to have potential in tackling calorific and VAD malnutrition problems of children and other vulnerable group (pregnant and breast-feeding mothers) in targeted communities.

Table 2.2 presents a contrast in the energy outputs between OFSP (Orange-Fleshed Sweet Potato) and other prevalent African crops. The roots of orange-fleshed sweet potatoes possess substantial carbohydrate content, yielding a greater amount of consumable energy per hectare per day compared to staple carbohydrate sources.

Table 2.2. Comparative Energy Yields of Sweet potato and Other Major Crops

Crop	Average Tropical Yield (Tons/Hectare)	Edible Energy Value (MJ/Kg)	Proportion of Edible Energy (%)	Edible Energy per Hectare (10^3 MJ)	Mean Growth Period (Days)	Edible Energy (MJ/ha/day)
Rice	2	14.8	70	20.8	140	149
Maize	1	15.2	100	18.8	130	145
Millet	<1	15.0	100	8.2	100	82
Cassava	9	6.3	83	45.6	330	138
Banana	13	5.4	59	41.4	365	113
Sweet potato	7	4.8	88	27.2	140	194
Sorghum	<1	14.9	90	11.1	110	101
Yam	7	4.4	85	26.2	280	94

Source: Woolfe (1992) as cited by Stathers et al. (2018)

It is important to appreciate the targeted efforts to enhance OFSP production and consumption as a recommended dietary intake in the fight of VAD. Table 2.3 presents a contrast in the nutritional attributes among sweet potatoes of various flesh colours, cassava roots, and maize grains.

Table 2.3. Nutritional Composition of Sweet potato, Cassava and Maize

Nutrients	Units/100g	Sweet potato				Cassava		Maize
		OFSP	Yellow Fleshed Sweet Potato	White Fleshed Sweet Potato	Yellow Fleshed Sweet Potato	White Raw Roots	Orange Grain	White Grains
Vitamin A (RAE)	µg	727	150	3	33	1	30	
Iron	mg	0.61	0.61	0.61	0.39	0.27	1.87	1.4
Zinc	mg	0.3	0.3	0.3	0.47	0.34	2.03	1.73
Protein	G	1.57	1.57	1.57	1.06	1.36	9.78	8.51

Source: USDA, 2003; Harvest Plus, 2010 as cited by Stathers et al. (2018)

OFSP are a valuable reservoir of vitamins, minerals, polyphenols, antioxidants, and anthocyanin. Malavi et al. (2022) found that incorporating varying proportions of OFSP puree into bread production enhanced nutritional value of OFSP composite bread. Table 2.4 and Table 2.5 exhibit an increase in beta-carotene, ash, and fiber levels within composite bread.

Furthermore, there was a noticeable enhancement in colour and microbial preservation characteristics of composite bread, as discussed by Malavi et al. (2022).

Table 2.4. Nutrient composition of wheat/OFSP composite bread and ingredients (on a dry weight basis, DWB

Treatment	Moisture (%)	Crude Fat (%)	Crude Protein (%)	Crude Fiber (%)	Ash (%)	Available Carbohydrates (%)	Energy (kcal/100g)
OFSP puree	67.5±0.4	0.6±0.1	5.2±0.0	5.0±0.2	4.3±0.1	84.9±1.2	365.5±4.7
Wheat Flour	10.4±0.3	2.3±0.1	10.2±0.1	1.4±0.1	1.8±0.0	73.9±1.0	357.1±3.2
Wheat bread (0:100)	28.6±0.9	5.4±0.0	10.6±0.0	1.2±0.1	1.9±0.1	80.9±1.2	414.5±4.7
OFSP bread (20:80)	29.1±0.5	5.0±0.0	9.9±0.2	1.8±0.0	2.4±0.0	80.5±0.8	406.6±2.5
OFSP bread (30:70)	30.8±0.7	5.1±0.1	10.0±0.2	1.8±0.1	2.5±0.0	80.6±1.1	407.6±5.1
OFSP bread (40:60)	31.9±0.5	5.4±0.3	10.4±0.2	1.7±0.1	2.8±0.2	79.6±1.1	408.7±1.9
OFSP bread (50:50)	32.7±0.8	5.5±0.2	10.4±0.5	1.8±0.2	3.2±0.1	79.1±1.8	407.0±5.1

Source*:* Malavi et al. (2022)

Table 2.5. Content of beta-carotene and Retinol Activity Equivalents in composite bread made from OFSP puree (DWB)

β-Carotene content (mg/100g)							
OFSP: Wheat Flour (%)	β-Carotene Crust	β-Carotene Crumb	13-cis β-carotene	All-trans β-Carotene	9-cis β-Carotene	Total β-Carotene	RAE, (µg/100 g)
Wheat bread (0:100)	Nd	nd	nd	nd	nd	nd	-
OFSP bread (20:80)	0.8±0.1	1.2±0.0	0.43±0.00	1.41±0.06	0.07±0.00	1.9±0.1	138.5±7.0
OFSP bread (30:70)	1.0±0.0	1.6±0.1	0.61±0.00	1.92±0.07	0.11±0.01	2.6±0.1	189.4±4±5.6
OFSP bread (40:60)	1.5±0.1	2.7±0.0	0.94±0.01	3.07±0.03	0.19±0.01	4.2±0.0	302.8±2.8
OFSP bread (50:50)	1.7±0.1	3.7±0.1	1.20±0.26	3.95±0.05	0.24±0.01	5.4±0.1	389.1±4.7

Source: Malavi et al., (2022)

Table 2.6 shows how vitamin A contributes proportionally to the dietary intake through the consumption of OFSP composite bread among various age groups. According to Malavi et al. (2022), consumption of 100g serving of 30% sweet potato bread provides roughly 47% of daily vitamin A requirement for adolescents and about 32% for children under the age of five. Similarly, this could address approximately 25% of the recommended daily allowance (RDA) for vitamin A for pregnant women and around 15% for lactating women.

Table 2.6. OFSP puree composite bread contribution to vitamin A RDA

OFSP Puree: Wheat Flour (%)	Children 4-8 Years	Adolescents 10-18 years	Adult Males 19-65 years	Adult Females 19-65 years	Pregnant Women	Lactating Women
White Bread (0:100)	0.0	0.0	0.0	0.0	0.0	0.0
Composite Bread (20:80)	34.6	23.1	15.4	19.8	18.0	10.7
Composite Bread (30:70)	47.4	31.6	21.0	27.1	24.6	14.6
Composite Bread (40:60)	75.7	50.5	33.6	43.3	39.3	23.3
Composite Bread (50:50)	97.3	64.9	43.2	55.6	50.5	29.9

Source: Malavi et al. (2022)

2.7.2 Bio accessibility of OFSP during preparation

Carotenoid bio accessibility refers to the proportion of carotenoids that are released from the food's structure, making them available for absorption by the intestinal lining (Brown et al., 2004; Reboul et al., 2006). The accessibility of β-carotene is influenced by multiple factors, including dietary fats, which are crucial for beta-carotene absorption and conversion to retinol (Stathers et al., 2018). Researchers like Bengtsson et al. (2010), Tumuhimbise et al. (2009), and Veda et al. (2006) similarly attribute carotene accessibility to aspects such as the food's composition, the types of fiber and fat present, and the mechanical breakdown during food processing. In the context of OFSP, the extent of carotenoid release from the food matrix hinges on the specific variety and processing techniques employed (Bengtsson et al., 2010;

Tumuhimbise et al., 2009). Notably, heat processing and maceration can enhance the bio accessibility of β-carotene from OFSP by disrupting the microstructure of the plant tissue thus releasing nutrients from the intricate food matrix (Tumuhimbise et al., 2009).

Figure 2.3 depicts impact of boiling and drying on beta-carotene levels in OFSP tubers as reviewed from different research papers. Studies indicated high conservations of >68% beta-carotene when tubers were cooked as compared to baking and microwaving. Generally, Sweet Potato preparation techniques conserved up to 75% of the beta-carotene inherent to the tubers (Stathers et al., 2018).

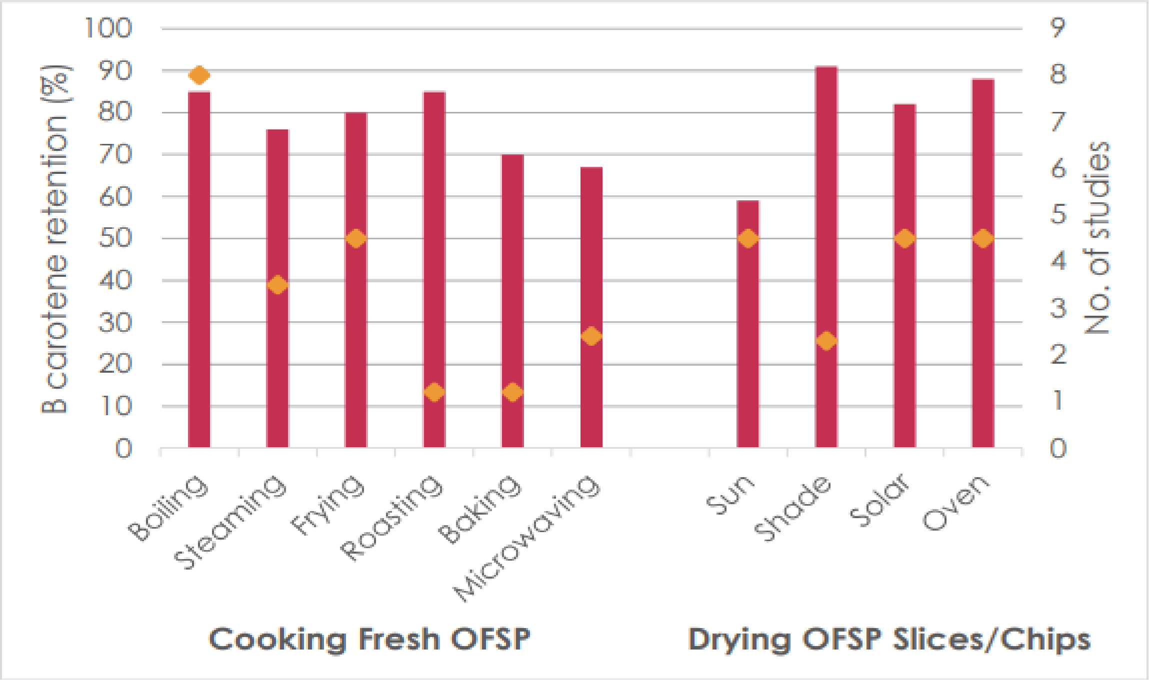

Figure 2. 2. Effect of heat preparation techniques on beta-carotene conservation in OFSP as reviewed by different research studies

Source: Stathers et al. (2018)

However, consumption of OFSP varieties rich in beta-carotene is encouraged to maximize vitamin A. According to Stathers et al. (2018), to mitigate the potential decline in beta-carotene caused by boiling small or peeled OFSP root pieces, it is recommended to opt for boiling whole unpeeled roots. This approach is beneficial due to the combined impact of the decreased surface area of the complete root and the protective influence of the peels.

2.8 The process of bread making

2.8.1 What is Bread?

Bread, a common dietary staple, is usually crafted from cereal flour, frequently derived from wheat. Apart from the essential ingredients used to make bread, supplementary ingredients are introduced across diverse global regions and cultures (Ngemakwe et al., 2015). Displaying a neutral flavor and aroma, bread represents a fundamental food item esteemed for its affordability, rich nutritional profile. Nutritional profiling (NP) models are developed to evaluate the nutritional value, calorie content, and the number of micronutrients and macronutrients contained in a given food accompanied by additional details on the nutritional anomaly provided by published standard nutrients and nutritional databases (Mondal et al., 2023).

2.8.2 Ingredients in Bread Making

2.8.2.1 Wheat flour

Wheat flour is the main ingredient in bread making and starch is its principal component ranging from 61% to 65% (Goesaert et al., 2008). Wheat flour for bread has starches and functional protein glutens that favour processing of leavened aerated bread, but is limited in fat and balanced amino acids (Jiang & Wang, 2005). The protein content in wheat primarily constitutes gluten, which contributes to the flour's high-water absorption and imparts cohesiveness and viscosity to the dough, facilitating efficient gas retention (Scherf & Koehler, 2016). This attribute accounts for the bread's substantial volume and distinctive crumb structure. During the kneading process, the flour initially absorbs water, transferring mechanical energy to the formation of gluten. This results in a continuous viscoelastic network of gluten interwoven with starch granules (Singh & MacRitchie, 2001). The quantity gluten proteins significantly influence wheat flour behavior during kneading and its capacity to tolerate mixing. Moreover, gluten dictates the rheological characteristics of a well-developed dough. Notably, the dough's resistance to extension plays a pivotal role in determining its gas retention capability, thereby influencing bread volume and crumb structure. Inadequately low or excessively high resistance to extension yields baked goods with diminished volume, where gas bubbles are either unstable and collapse or are unable to sufficiently expand. Flours sourced from alternative cereal species or wheat-composite flours lead to bread with reduced volume, smaller pores, and less elasticity when prepared using standard recipes, because of dilution of gluten concentration, which reduces viscoelastic properties of wheat flour (Day et al., 2006). Selvakumaran et al. (2019) reported that substitution of wheat flour with OFSP puree in brownies formulations significantly increased total dietary fiber, specific volume, moisture, and fat content.

2.8.2.2 Water

Water is critical in production of bakery and confectionery items. It is utilized to hydrate flour particles, enabling interaction among flour components and resulting in a uniform dough mixture. During mixing, water is crucial for forming the dough and is evenly distributed among the flour constituents to enhance its fluidity. The remaining water forms a 'free' water phase, serving to hydrate flour proteins, primarily the damaged starch fraction, and soluble elements like sugars, salt, and proteins. Additionally, it aids in dispersing yeast cells (Schiraldi & Fessas, 2012). The quality of flour significantly affects the amount of water absorbed by the dough. Throughout fermentation, water serves a solvent role within the dough. Numerous reactions occurring in this stage rely on the presence of a solvent. For instance, water dissolves a portion of the free CO_2, leading to formation of carbonic acid. This donates to the dough's mildly acidic pH, establishing an environment conducive to enzymatic and yeast activity within the dough system

2.8.2.3 Salt

Salt, commonly in the form of sodium chloride, constitutes a portion of the dough's ingredients. The quantity of salt utilized typically ranges from 1.0% to 2.0% in relation to the flour weight (Tuhumury, 2011). Salt contributes to firmness of the dough and mitigates stickiness. Furthermore, salt improves wheat dough resistance to mixing hence extending dough development duration (Uthayakumaran et al., 2011). It serves a crucial role in strengthening the dough (Preston, 1989), thereby impacting the bread crumb's slicing properties (Arendt et al., 2007; Belz et al., 2012; Ngemakwe et al., 2015)

2.8.2.4 Yeast

Yeast, specifically Saccharomyces cerevisiae, is utilized within the baking industry for its capacity to generate carbon dioxide through the breakdown of glucose (Gray & Bemiller, 2003). In the initial stages of fermentation, starch and sugars present in the dough are hydrolyzed into glucose and maltose by the enzyme amylase. In an anaerobic environment, yeast ferments glucose, yielding carbon dioxide and alcohol as byproducts. Carbon dioxide produced enters the dough matrix, becoming saturated before being released into gas cells developed during dough mixing. These gas cells facilitate the dough's expansion to achieve the desired volume by exerting pressure on the internal gluten network. Secondary fermentation yields alcohol and other compounds, including organic acids, aldehydes, and ketones, which serve as building blocks in the development of taste and flavor (Ngemakwe et al., 2015).

2.8.2.5 Sugar

Sugar in bread serves a dual purpose – beyond its role as a sweetener, it functions as a substrate during the initial fermentation stages and contributes to the formation of a brown crust through caramelization. The amount of sugar introduced has an impact on the elasticity and stability of the dough (Ngemakwe et al., 2015). Dewettinck et al. (2008) further attributed the distinct flavor profile of bread to a number of compounds generated from critical interactions between sugars and amino acids during baking.

2.8.2.6 Shortening

Shortening, present as fats or oils, plays a role in the dough's rheological characteristics, consequently influencing loaf volume by enhancing oven spring, leading to a softer crumb, reduced crust crispness, and improved bread shelf life (Ngemakwe et al., 2015). The texture of crumb and smoothness of crust are determined by quantity of added fat (Ngemakwe et al., 2015).

2.8.2.7 Improvers

Ascorbic acid (Vitamin C) as an improver is a reducing agent and is susceptible to oxidation into dehydroascorbic acid (DHAA) when water is added to flour. Wheat flour contains endogenous ascorbate oxidase enzymes that rapidly oxidizes ascorbic acid to dehydroascorbic acid during mixing of dough due to incorporation of plenty. The oxidation of ascorbic acid to DHAA possibly leads to the formation of reactive intermediates (e.g. superoxide anions) that can generate thiol radicals by cleaving wheat proteins. These thiol radicals re-associate forming new strong intramolecular disulfide bonds between the gluten proteins which connect gluten network that are crucial for good strength dough. Sweet potato in comparison to wheat flour has low protein content (sweat potato: 1.6g/100g and wheat flour: 12g/100g portion) and a high vitamin C content (2.5mg/100g portion) in comparison to an insignificant amount of vitamin C in wheat flour. Ndayishimiye et al. (2016) proposed the utilization of ascorbic acid in the preparation of sweet potato-wheat bread, primarily due to its impact on mixing characteristics, particularly on dough stability, dough development time, and protein interaction attributes.

2.8.3 OFSP puree as an ingredient in the bread making process

In Sub-Saharan Africa, specifically in Kenya and Rwanda, bakeries are integrating OFSP puree as a partial replacement for wheat flour within their bread manufacturing processes (Bocher et al., 2017). To extend shelf life of sweet potatoes, production of flour through drying has been employed, offering advantages like reduced perishability, convenient storage, and transport. However, this drying is accompanied by notable carotenoid loss (Bengtsson et al., 2010; Nzamwita et al., 2017). Preference of OFSP puree over OFSP flour has showcased advantages encompassing reduced energy usage and conversion rates, preservation of nutritional components like beta-carotene levels, augmentation of sensory attributes like colour and flavor, and advancements in quality markers like volume and texture (Sindi et al., 2013). Muzhingi et al. (2016) determined that bread incorporating OFSP puree exhibited the highest concentration of all-trans β-carotene at 3.14 mg/100g in terms of dry weight (dw), in contrast to OFSP flour bread which contained 0.08 mg/100g (dw). In a survey done in Kenya to profile consumer acceptability of orange-fleshed sweet potato bread, Wambui (2017) as referenced by Owade et al (2018) indicated that OFSP puree bread was highly accepted. At present, fresh OFSP puree is utilized as an ingredient in bakery applications in Kenya. It reaches consumers in the form of vacuum-sealed, shelf-stable OFSP puree that includes preservatives, enabling it to maintain its quality for four months stored at room temperature (Bocher et al., 2017).

2.8.4 Bread making process

Four distinct methods can be employed to produce bread: traditional Straight Dough Fermentation, two-stage Sponge Dough Method involving creation of sponge from a portion of ingredients, Rapid Processing Method utilizing diverse active ingredients and processes, and Mechanical Dough Development Method which employs high-speed mixing to achieve dough development without a fermentation period (Cauvain, 2007; Cornell & Cauvain, 2003; Sedláček & Horčička, 2011).

Onuegbu et al. (2013) undertook a study to examine the impact of diverse bread-making methodologies (rapid process, straight dough, sponge and dough, sourdough) on both the baking process and sensory attributes of composite wheat-maize bread. The investigation focused on varying levels of maize flour incorporation, spanning from 0% to 20%. The study revealed that among the assessed methods, the rapid processing technique garnered the highest preference in relation to multiple sensory characteristics and overall likability. The sponge and dough approach yielded optimal instrumental and sensory crumb texture, while differences in crust colour were minimal between the rapid processing and sourdough methods. Furthermore, the investigation highlighted that there were no notable differences in crumb texture among composite breads crafted through the rapid processing dough, straight dough, and sourdough methodologies.

This research will apply bread making using the straight dough bulk fermentation method because it is convenient and yields high quality bread. Awuchi et al. (2019) noted that the bread-making process involving composite flour and wheat flour is perceived to be the same, encompassing primarily three key phases: mixing or dough formation, fermentation, and baking (Figure 2.3).

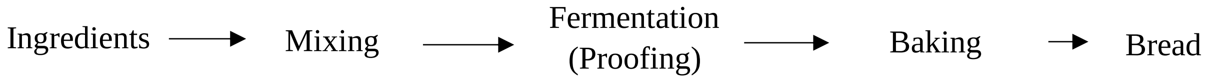

Figure 2. 3. General flow diagram of making bread

2.8.4.1 Process of mixing

The process of mixing plays a crucial role in amalgamating ingredients into a uniform dough mass, infusing air into the mixture, and fostering the development of gluten proteins into a cohesive structure (Cauvain, 2007). In the mixing phase, the addition of water initiates the hydration of dry ingredients, facilitating the diffusion of moisture into the flour. This results in the interaction of hydrated flour particles, leading to the removal of their outer layers through rubbing. Over time, this process leads to the hydration of flour components, particularly proteins and starch, which contributes to dough development (Meerts et al., 2017). Belton (1999) introduced the "loops and trains" model to clarify how dough behaves concerning the hydration of gluten proteins. At lower hydration levels, proteins lack a defined arrangement and interact closely through hydrogen bonds, without a structured pattern. In the middle hydration range, the system becomes more pliable, enabling the development of hydrogen-bonded structures with a relatively low ratio of loops to trains. At higher hydration levels, a profusion of hydrogen bonding takes place, leading to the creation of areas with disrupted interactions between protein chains. This is identified by a high loop-to-train ratio, indicating elevated viscoelastic properties in highly hydrated flour.

2.8.4.2 Fermentation process

The dough that is formed and developed during mixing expands through the generation and retention of gas within its structure during proofing, ultimately solidifying during the baking process (Cauvain, 2007, Cornell & Cauvain, 2003;). Fermentation unfolds in two phases, encompassing bulk fermentation, also termed the first proof or knockdown, and the primary fermentation, often referred to as the final proof. In the bulk fermentation stage, the dough undergoes a period of rest following mixing and preceding division, typically ranging from 30 minutes to 3 hours (Ćurić et al., 2014). This interval is intended to improve the dough's elasticity and strength, rendering it easier to stretch without tearing during the shaping process (Cauvain, 2007). After the resting period, the main dough can be separated into individual portions by measuring their weight, after which they are shaped and placed in baking tins or baking trays. The shaped dough is then positioned within a proofing cabinet for continued fermentation, constituting the final proof. This phase is essential for working the fermented dough, segmenting formed gas cells, and ensuring a constant distribution of these cells. During the final proofing phase, which usually extends for approximately 30 to 60 minutes, enzymes gradually transform starch from the flour into sugars and dextrins (Ćurić et al., 2014). These sugars act as sustenance for the yeast, resulting in the production of carbon dioxide and ethanol as byproducts. The buildup of carbon dioxide causes the dough to rise and retain this gas, requiring the dough's surface to maintain its elasticity.

2.8.4.3 Baking process

The concluding phase of bread production is baking, during which the dough undergoes a transition into bread by undergoing structural firming and the creation of characteristic aromatic compounds through the application of heat. This procedure occurs within temperature intervals spanning from 220 to 250°C (Cornell & Cauvain, 2003; Ćurić et al., 2014). While inside the oven, the dough undergoes a series of transformations attributed to the rise in temperature. Initially, yeast activity halts at 55°C, followed by the expansion of trapped air that leads to a stable structure. At around 60°C, starch starts to undergo gelatinization. The starch granules absorb free water present in the dough, including water from protein membranes, until complete gelatinization is achieved (Cauvain, 2007). Adequate baking requires attaining a final internal temperature within the range of 92 to 96°C, ensuring a thoroughly cooked loaf (Cornell & Cauvain, 2003; Ćurić et al., 2014). The fluctuating temperatures encountered within and outside the dough play a role in shaping both the crust and crumb of the bread. The baking process encompasses distinct phases, including oven spring (the zone of active enzymes), starch gelatinization, and the development of browning and aroma. The creation of the crust holds significance in both fortifying the bread's structure and fostering flavor enhancement (Cauvain, 2007).

2.9 Bread quality

2.9.1 Sensory quality of bread

Stone & Sidel, (2004) defined sensory evaluation as “the scientific discipline used to evoke, measure, analyze, and interpret human reactions to those characteristics of foods and beverages as they are perceived by the senses of sight, smell, taste, touch, and hearing. The most widely used method of assessing product acceptability is based on overall liking (or dislike) scores using a 9-point Hedonic scale (Gámbaro, 2012). The Hedonic scale has been used in acceptability studies of different products as well as for sensory psychophysical and intercultural studies (Nicolas et al., 2010). The data obtained from this test can be used in development of food products and as criteria of launching new products in the market (Nicolas et al., 2010).

The collective appearance encompasses observable sensory characteristics such as colour, size, shape, and texture (Jeleń & Gracka, 2016). Flavor encompasses a range of sensory attributes, encompassing elements such as taste, aroma, and sweetness. Aroma, to be precise, refers to the scent of a food item, resulting from volatile compounds traveling through the nasal passages when inhaled (Jeleń & Gracka, 2016). Texture represents a foundational characteristic that, alongside visual appearance, taste, and aroma, constitutes the sensory excellence of food items (Costell et al., 2009). It encompasses tactile attributes, evaluated through geometric features, mechanical properties, and moisture content, all perceived by tactile nerves on the skin's surface, including the hand, lips and tongue (Jeleń & Gracka, 2016). This encompasses attributes like airiness, crispness, crumbliness, chewiness, tenderness, firmness, and moisture content. The overall preference can be characterized as a multifaceted expression of favorability towards the product as a cohesive entity.

2.9.2 Physical properties of bread

Loaf volume serves as a measure of fresh bread quality in research, industry quality control, and consumer assessments (Chin & Campbell, 2005). Conversely, specific volume of bread loaves provides a standardized foundation for comparing findings across different studies (Oyeku et al., 2008). The specific volume offers insights into the bread's gluten content (Van Hal, 2000) along with constituents like starch and fiber. According to studies, soft wheat flour produces lower loaf volumes when used to make bread. Furthermore, the variance between weak and strong flours has been attributed to differences in the molecular mass distribution of their proteins (Bonilla et al., 2020). An abundance of glutenin molecules with extended chains was observed to foster high extensibility in the protein phase and consequently in the dough (Bonilla et al., 2020).

Throughout the proofing and baking of bread, there is typically a loss of weight, which could stem from both fermentation losses induced by starch amylases and the utilization of soluble sugars by yeast, as well as moisture evaporation during baking (Bakare et al., 2016). However, research suggests that weight loss tends to diminish with an increase in non-wheat flour substitution within composite flours. This phenomenon might be attributed to higher weights attributed to these flours, which possess the ability to create viscous dough and absorb substantial water quantities, subsequently released during the baking process (Bakare et al., 2016).

2.9.3 Nutritional composition of bread

Bakery products are carbohydrate-rich due to their high starch and simple sugar content. The carbohydrate levels are influenced by the flour's chemical composition and the quantities of sugars introduced during baking. Bread is rich in dietary fiber ranging between 0.3 and 1.5g/100g dependent on the flour type used (Almeida et al., 2013). As a result, whole meal breads present elevated dietary fiber levels. Dietary fibers, comprising mainly cellulose and hemicelluloses, are indigestible within the human gastrointestinal tract. However, they positively impact intestinal peristalsis and facilitate the expulsion of harmful metabolites. Flour composition and dietary fiber content further influence the concentrations of other nutrients. Whole meal wheat and rye breads contain 2 to 5 times more iron, magnesium, manganese, copper, and zinc salts compared to white bread (Almeida et al., 2013).

Protein content varies between 4.5 and 8.0 g/100 g of fresh bread. The fat content in bakery products is generally low, ranging from 0.7% to 2.5%. This contributes to the relatively extended shelf life of bread. Bread is notably rich in B complex vitamins, particularly thiamine (vitamin B1), niacin, riboflavin, and folic acid, as well as vitamin E. Whole meal breads, especially yeast-fermented wheat breads, harbor higher levels of these essential nutrients. The energy value of bread spans from 874 to 1924 kJ, equivalent to 208-459 kcal/100 g of fresh product, with the exception of certain types like pumpernickel and crisp breads, which possess higher energy values and nutrient content (Diowksz et al., 2000).

2.10 Composite technology

2.10.1 What are composite flours?

Composite flours refer to a combination of flours, starches, and other components meant to replace wheat flour entirely or partially in baking and pastry products (Milligan et al., 1981). Coined from the 'Composite Flour Program' initiated by the Food and Health Organization (FAO) in 1964, the concept of composite technology emerged with the primary aim of curbing support costs for temperate regions. The FAO emphasized that adopting composite flour in various food products could yield economic benefits by potentially reducing or even eliminating wheat imports. This approach could also fulfill the demand for bread and pastry products through the utilization of domestically cultivated resources instead of relying solely on wheat (Jisha et al., 2008b).

2.10.2 Bread from wheat composite technology

Noticeably, when a foreign substitution is added to the wheat flour fraction of the bread making process, a decrease in baking performance is registered. This is because a certain quantity and quality of the gluten proteins must be present for a flour to form a dough cohesive enough to trap the gas produced during the fermentation process and to produce an acceptable bread (Mutambuka, 2008).

The majority of prior research focused on employing composite flour for bread production has primarily centered on assessing how the biological source of the flour and the extent of substitution of wheat flour impact the quality of bread produced (Shittu et al., 2014). The composite flours investigated in these studies comprised either two or three types of flour, involving combinations of flours from various crops, often including or excluding wheat flour. According to Shittu et al. (2014) a general trend was noticed: Increased replacement of wheat flour for non-wheat flour resulted in lower loaf volume and degraded sensory qualities such as appearance, texture, and flavor. The study also highlighted variances in bread-making potential among different varieties of the same crop.

Elkatry et al. (2023) demonstrated that wheat-sweet potato peels or flour blends at 10%, 20%, and 30% levels, exhibited elevated levels of elemental concentrations, bioactive compounds, and antioxidant capacity in comparison to bread made solely from 100% wheat flour. Furthermore, Elkatry et al. (2023) revealed that composite blends resulted in dough mixes with better rheological qualities than bread made entirely of wheat flour. The sensory attributes of the produced bread products were comparable

2.10.3 Rheological characterization of wheat composite dough

Rheological properties are used to predict the baking qualities of wheat and composite flours. It is a good predictor for the loaf volume and crumb properties of resultant breads (Guo et al., 2021). Dough rheological measurements in particular, relate to ease of dough handling and formulation. Dough is a material that is characterized by complex composition and internal structure. The process of mechanical processing, especially in dough forming, is significantly affected by its technological properties stemming from the physicochemical composition and the method of preparation (Chwarścianek, 2006). The most commonly used instruments in the measurement of dough rheological properties are rapid visco-analyser, farinographs, consistograph, alveograph and the mixolab.

Rheological properties are used to predict the baking qualities of wheat and composite flours. The pasting temperatures, for example, provide the food processor with information regarding the necessary baking temperature to ensure the dough is heated beyond its gelatinization point (BeMiller, 2011). During this heating/baking phase, starch in the dough absorbs water swells and bursts resulting into increased viscosity, translucency of the dough matrix and increased solubility (Shimelis et al., 2006). The maximum viscosity attained during heating phase is the peak viscosity and influences texture of composite bread (Bakare et al., 2016). The peak viscosity value also serves as an indicator of alpha amylase activity and other factors that contribute to it, including the inherent vulnerability of the starch to amylase and the strength of the starch gel (Meera, 2010). Holding strength on the other hand is an indicator of the ability of the starch granules to maintain their gelatinized structure when the paste is held at 95°C for 2min 30s under mechanical shearing stress (Bakare et al., 2016).

During dough processing, mixing induces alterations in dough's resistance to deformation, elasticity, extensibility, and stickiness) that enhance the dough's capacity to retain the carbon dioxide gas generated during yeast fermentation.

The Alveoconsistograph measures water absorption and consistency of the dough during mixing which are critical in the evaluation of the quality of dough thus bread quality. Water plays a crucial role in hydrating various components of the flour, including starches, non-wheat sourced fiber, damaged starch, and protein fibrils. Additionally, it aids in facilitating interactions between the crosslinks of proteins and the disulfide bonds during the process of dough mixing. Water absorption refers to quantity of water needed to attain maximum torque during dough development, which is characterized by fully developed gluten (Malomo et al., 2013). Hence, the optimal quantity of water required to create cohesive, viscoelastic dough with optimal gluten strength varies based on the composition of wheat or its alternatives. Partial substitution of wheat in composite blends in bread making has been reported to cause increase in water absorption of the composite flours (Malomo et al., 2013).

2.11 Process and product screening

Experimental designs function as structured methodologies providing notable benefits in recognizing significant variables affecting both products and processes through a factor screening technique. This method assists in distinguishing between low-risk and high-risk factors using well-founded statistical principles.

Screening designs are streamlined experimental techniques with the objective of identifying pivotal variables from a multitude of potential factors. Widely used screening designs encompass fractional factorial design, Taguchi design, and Plackett-Burman design, all are efficient when it comes to time and resource allocation.

2.11.1 Importance of screening

Screening designs provide a means to extract maximum information from a minimal number of experiments, thereby conserving resources and time and enhancing experimental efficiency. These designs are adept at revealing both main effects and interaction effects among factors (Beg et al., 2017).

Screening designs are usually implemented with reduced complexity to minimize the quantity of necessary experiments. In this context, designs of Resolution III or IV are often utilized, with Resolution III designs proving especially advantageous for investigating a wide range of factors within a manageable number of experimental trials. The utilization of low resolution is dictated by practical considerations, as conducting a large number of experiments is often impractical due to resource constraints. Nevertheless, employing low-resolution designs introduces a degree of bias in the experimental outcomes, leading to potential aliasing and confounding of main effects with false interactions. In Resolution III screening designs, main effects are confounded with two-factor interactions, while in Resolution IV designs, they are confounded with three-factor interactions. Although lower resolution enhances confounding control, it necessitates more experimental runs compared to Resolution III designs. Consequently, Resolution IV designs are often preferred as they strike a balance between reduced accuracy and better control over confounding, making them a superior choice over Resolution III designs (Beg et al., 2019).

Since screening designs are universally recognized as low-resolution experimental methodologies, they inherently involve the utilization of merely two levels for each individual factor. The rationale behind this is to optimize the efficiency of experimental runs, necessitating the use of the minimum number of levels, which is two. This translates to the inclusion of low level (-1) and high level (+1) settings for the factors. Notably, intermediate levels (0) are excluded from screening designs due to their limited utility in enhancing model fitting and resolution within this context.

2.11.2 Fractionated factorial designs

Fractionated factorial designs represent a subtype of screening experimental approaches, wherein a subdivision of complete experimental runs from full factorial design is chosen. The fraction is determined by the concept of factor sparsity, enabling these designs to efficiently pinpoint significant factors in an experiment. Unlike full factorial designs, fractionated factorial designs achieve efficiency by conducting a reduced number of runs for the experiment, thereby conserving time, resources, as well as effort.

The number of experimental runs in a fractionated factorial design is determined using the formula $X^{k\text{-}n}$, where “X” represents the number of investigated factor levels, “k” denotes the sum of factors being studied, and “n” indicates degree of fractionation. The range of factors considered in fractionated factorial designs can span from 3 to 21, while the levels for each factor are consistently set at 2. The extent of fractionation varies between 1 and 16, depending on the desired resolution level.

Fractionated factorial designs are particularly well-suited for optimizing both qualitative and quantitative aspects of products and processes. The two levels used in these designs are; low level (-1) and high level (+1). It's important to note that fractional factorial designs exclusively incorporate the factorial points located at various positions within the cubic structure of the design.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Experimental materials

Mature, non-damaged and disease-free orange–fleshed sweet potato (OFSP) roots (varieties: NASPOT 13O and NKB135) freshly harvested, were obtained from a research and demonstration farm at National Crops Resources Research Institute (NaCCRI) in Namulonge, Wakiso District. The harvested roots (1kg) were promptly transported to the laboratory, where they were stored in a cool and dry environment. Processing took place within five days of harvesting to prevent postharvest changes. Wheat flour (with 1g/kg of improver) was bought from Bakhresa Grain Millers Limited, Uganda. Salt, Sugar, baking powder, yeast, baking fat and ascorbic acid were purchased from local retail outlets in Banda, Kampala.

3.2 Experimental design

Tables 3.1 and 3.2 show the factor levels of the rheological and baking experimental design respectively. Design-Expert Version 13.0 software (Stat-Ease Inc, Minneapolis, MN, USA) was used to generate the experimental designs.

Table 3. 1. Factors, and levels of the Rheological Experiment

Factors	Levels
Puree	20 – 50%
Treatment	Pasteurized, Fresh
Variety	NATSPOT13O, NKB135

Table 3. 2. Factors and levels for Baking Experiment

Factors	Levels
Sugar	0 – 2%
Salt	1 – 2%
Fats	3 – 6%
Yeast	0.5 – 1%
Puree	20 – 50%
Ascorbic acid	0 – 0.01%
Variety	NATSPOT13O, NKB135
Treatment	Pasteurized, Fresh

Tables 3.3 and 3.4 show fractional factorial designs with 3 factors (1 numerical factor and 2 categorical factors) for rheological and 8 factors (6 numerical factors and 2 categorical factors) for the baking experiment at two level (2^{8-3}) of resolution IV, giving a total of 32 runs and 8 runs for the baking experimental design and rheological experimental design respectively.

Table 3. 3. Fractional Factorial Design used for the Rheology Experiment

RUN	PUREE	VARIETY	TREATMENT
1	50	NKB135	pasteurized
2	20	NKB135	pasteurized
3	50	NATSPOT13O	fresh
4	50	NATSPOT13O	pasteurized
5	20	NATSPOT13O	fresh
6	20	NATSPOT13O	pasteurized
7	50	NKB135	fresh
8	20	NKB135	fresh

Table 3. 4. Fractional factorial design used for the Baking Experiment

RUN	SUGAR (%)	SALT (%)	FAT (%)	YEAST (%)	PUREE (%)	ASCORBIC ACID (%)	VARIETY	TREATMENT
1	0	1	3	1	50	0	NKB135	fresh
2	2	2	3	1	20	0	NKB135	fresh
3	0	1	3	0.5	50	0	NATSPOT13O	pasteurized
4	2	1	3	1	50	0.01	NATSPOT13O	fresh
5	0	2	6	1	50	0	NATSPOT13O	fresh
6	2	1	6	0.5	50	0	NKB135	fresh
7	2	2	3	0.5	20	0	NATSPOT13O	pasteurized
8	0	2	3	1	20	0.01	NATSPOT13O	fresh
9	2	2	6	0.5	50	0.01	NATSPOT13O	pasteurized
10	0	1	6	0.5	20	0.01	NATSPOT13O	pasteurized
11	0	1	6	1	20	0.01	NKB135	fresh
12	0	1	3	0.5	20	0	NATSPOT13O	fresh
13	0	2	3	0.5	20	0.01	NKB135	pasteurized
14	0	2	3	1	50	0.01	NATSPOT13O	pasteurized
15	2	2	3	1	50	0	NKB135	pasteurized
16	2	1	6	1	20	0	NATSPOT13O	fresh
17	2	2	6	0.5	20	0.01	NATSPOT13O	fresh
18	2	1	3	1	20	0.01	NATSPOT13O	pasteurized
19	0	2	6	1	20	0	NATSPOT13O	pasteurized
20	2	1	6	1	50	0	NATSPOT13O	pasteurized
21	2	2	3	0.5	50	0	NATSPOT13O	fresh
22	2	1	3	0.5	50	0.01	NKB135	pasteurized
23	2	1	3	0.5	20	0.01	NKB135	fresh
24	0	2	6	0.5	50	0	NKB135	pasteurized
25	0	2	6	0.5	20	0	NKB135	fresh
26	2	2	6	1	20	0.01	NKB135	pasteurized
27	2	2	6	1	50	0.01	NKB135	fresh
28	2	1	6	0.5	20	0	NKB135	pasteurized
29	0	1	6	0.5	50	0.01	NATSPOT13O	fresh
30	0	1	6	1	50	0.01	NKB135	pasteurized
31	0	1	3	1	20	0	NKB135	pasteurized
32	0	2	3	0.5	50	0.01	NKB135	fresh

3.3 OFSP puree preparation

The roots were sorted cut, and carefully rinsed with clean water before being separated into two equal halves. One portion (500g) was sliced (sterilized hand operated sharp kitchen knives) into sizable cubes convenient for grating. The cubes were grated (using a stainless-steel hand operated kitchen grater) into small shreds and then mashed with a heavy-duty blender (Model: WK-1710-4, Sokany, China) to make a homogenous puree.

The second portion (500g) of the unpeeled OFSP was subjected to heat treatment (HTST) at 96.6°C for 15 minutes (using a Russel Hobbes Satin Quartz 3 Tier Food steamer, model No: 10969, Yiwu, China) and then cooled for sixty minutes on a clean sterilized plastic kitchen tray. The tubers were then subjected to mashing and refrigeration as the first portion.

3.4 Process of making bread

Bread was manufactured using the straight dough technique as per the AACC method 10-10.03 (AACC, 2010), incorporating adjustments from Owade et al. (2018). Ingredients were weighed using a digital scale and mixed with required amount of water in a Macadams spiral dough mixer (SM 201S/1917220822, Johannesburg, South Africa) for 15 min. After mixing, the dough was divided into ≤500 g portions, rounded, fermented (knocked back), molded into a loaf shape and placed in a lightly greased bread tin. The baking tin was positioned inside a Macadams proofer (model MP01-05906-05/19, Johannesburg South Africa) and allowed to undergo proofing at a temperature of 40°C and relative humidity of 80% for a duration of 30 minutes. Subsequently, the proofed dough was placed into a preheated Macadams rotary oven (model M120, Johannesburg, South Africa) and baked at 200°C for a period of 30 minutes. After baking, the bread was cooled for 24 h, placed in low-density polyethylene bag and analyzed for physical, nutritional and sensory properties as described in sections 3.5 – 3.8.

3.5 Determination of nutrient profile of composite bread

Standard AOAC methods were used for determining chemical composition (vitamin A, starch quantity, crude fiber, total protein content, reducing sugars, total carotenoids content and β-carotenoid content) of the composite bread as described in the subsequent subsections below. Modifications were made to suit the sample differences.

3.5.1 Measurement of crude fiber

The amount of crude fiber in the composite bread samples was determined using the AOAC 978.10 methodology (AOAC, 2000). Two grams of sample without fat were introduced into a pre-weighed 50 mL falcon tube. The mixture was then subjected to digestion in a water bath at reflux temperature (50°C) using 25 mL of 2.5 M H_2SO_4 for a duration of 30 minutes. The mixture was cooled at room temperature by placing the samples in a bath of water at room temperature for further 30 minutes followed by centrifugation at 6000 rpm for 30 minutes at 4^o C while decanting off the supernatant. The subsequent phase of digestion was carried out using a solution of 2.5 molar NaOH. The mixtures were cooled again by placing the samples in a bath of water at room temperature for further 30 minutes followed by centrifugation at 6000 rpm for 30 minutes at 4^o C while decanting off the supernatant. The residue within the 50 mL falcon tube was washed with 3 mL of ethanol and then dried at 105°C to achieve a consistent weight, W_1. The oven-dried sample residues were subsequently cooled in a desiccator at room temperature and reweighed. The percentage crude fiber content was calculated as below.

$$\textbf{Crude Fiber}\ (\%) = \frac{\textbf{W1} - \textbf{W2}}{\textbf{Sw}} \times \textbf{100}$$

Where W_1 is the weight of the empty 50 mL falcon tube before incineration; W_2 is the weight of the falcon tube after incineration and S_w is the weight of the samples before drying

3.5.2 Determination of vitamin A

Vitamin A content was determined using the method reported by Jadoon et al. (2013) with modifications. Pharmaceutical solid vitamin A tablet was ground with a sterilized mortar and pestle. Thereafter, known quantity (0.5 g) of the ground material sample was weighed with a weighing balance model (KERN ADJ 100-4, KERN & SOHN GmbH, Ziegelei 1,72336 Balingen, Germany) and vitamin A was extracted twice with 5.0 mL of 80% methanol to a total of 10 mL and vortexed for uniform mixing with a vortex mixer. A volume of 5 mL was pipetted off into a clean and empty 50 mL falcon tube where 10 mL of 80% methanol was further used for dilution. The mixture was wrapped with an aluminum foil to prevent light mediated degradation while in the 50 mL falcon tube.

The mixture was saponified with addition of 1.0 mL of 50% KOH and 2.0 mL of 80% ethanol and incubated in a water bath at 45°C for 2 h. After incubation, distilled water of 1.0 mL was added to the mixture and re-vortexed. To the mixture, 5.0 mL absolute petroleum ether was added, vortexed and left to settle for five (5) minutes till formation of the two distinct organic layers. The organic layer on top was evaporated to dryness with the help of the rotary evaporator model R 3.10, where the water bath was set at 37°C and rotation of the arm set at 100 rpm. The mixture was re-dissolved by vortex mixing after adding 5 mL of carrier solution composed of 80% methanol in triton solution. Similar procedures were used for bread samples. From the solution, 1 mL was pipetted off into a cuvette after which absorbance recorded spectrophotometrically at 562 nm using a UV/Vis spectrophotometer (Jenway, 6505, UK).

3.5.3 Determination of starch

Starch content was determined using the phenol-sulphuric acid method according Shingala et al. (2022). A quantity of 0.2 g of ground bread sample was weighed in to a falcon tube. This was followed by 1 mL 80% hot ethanol to separate sugar and thereafter, vortexed for 30 seconds to ensure efficiency in extraction. Clarification was further carried out at 6000 rpm for 10 minutes at +4°C with the HERMLE Benchmark Centrifuge (Z 326 K, Germany) and decanted off. To the sediment, the sediment mixed with 7.5 mL of concentrated perchloric acid and allowed to stand for 1 h. The resultant solution was then added 17.5 mL of distilled water and the solution vortexed. Subsequently, an aliquot of 0.5 mL was pipetted off into a clean 50mL graduated plastic Falcone tube followed by of 0.9 ml of distilled water.

0.5 mL of 5% phenol was added to the mixture and thoroughly mixed. Subsequently, concentrated sulphuric acid (2.5ml) was added, gently shaken for uniform mixing and left in the dark for 10 minutes at room temperature. Spectrophotometric absorbance per bread sample was recorded at 490 nm using UV/Vis jenway 6305 spectrophotometer, (Bibby Scientific Ltd, Dunmow, Essex. CM6 3LB, UK). The standard curve was plotted using 0 –100 μg standard glucose solution and amount of starch determined using the formula below.

$$\mathbf{Starch} = \frac{\mathbf{0.05 \times A \times 1/M \times 0.9}}{\mathbf{Weight\ of\ the\ sample}} \times \mathbf{100}$$

Where A is the absorbance, M is the slope of standard curve

3.5.4 Determination of total protein content

For the accurate assessment of total protein content in the composite bread samples, a trisma-Base Buffer, as detailed by Gokaltun et al. (2023), was employed as an extraction medium. Minor adjustments were made to the procedure. Two alkali extractions were prepared. Briefly, 500 (±0.01) mg of milled bread samples were weighed into centrifuge tube (50mL). To the tube, 5mL of 100mM Tris-base and slurry were vortexed for 5 minutes and orbital shaken for 30 minutes under continuous periodical agitation. The mixture was thereafter centrifuged at 6000 rpm for 30 minutes and at 4ºC to obtain a clear clarified organic extract. Quantification of protein meanwhile was carried out with the Biuret protein assay calorimetry technique according to Arunima and Verulkar (2022). To an empty 50 mL falcon tube, 4 ml of Biuret reagent was added to match standard calibration curve prepared using Bovine serum albumin.

Spectrophotometric absorbance readings for Optical density were then taken at 545nm wavelength with UV/Vis jenway 6305 spectrophotometers, (Bibby Scientific Ltd, Dunmow, Essex. CM6 3LB, UK).

3.5.5 Measurement of reducing sugars

To extract soluble sugars, 10 ml of 80% ethanol was added to conic centrifuge tubes and heated at 80 °C for 40 minutes in a water bath. After cooling and centrifugation, the resulting supernatant was carefully transferred to smaller centrifuge tubes for further analysis. The quantification of soluble sugars was conducted using the anthrone method, employing a standard curve created with varying concentrations of glucose solutions. Different volumes of the extracts were transferred to new tubes, appropriately diluted, and maintained at a low temperature during the entire reaction process. Subsequently, 3 mL of anthrone reagent (consisting of 0.2 g anthrone dissolved in 100 mL of 80% ethanol) was introduced to each tube, followed by incubation. Afterward, the samples were allowed to cool, and absorbance measured at 625 nm (Pandita & Pandita, 2023)

3.5.6 Quantification of total carotenoids content

Total carotenoid content (TCC) analysis was conducted on fresh samples following the protocol by Atwijukire et al. (2019) using the iCheckTM carotene kit developed by BioAnalyt Laboratory (http://www.bioanalyt.com). The methods initially established for cassava roots (Esuma et al., 2016) were adapted for analyzing the composite bread samples and determining their total carotenoid content (TCC). In this procedure, 5 g of the ground composite bread samples were precisely weighed using a KERN ADJ 100-4 weighing balance (KERN & SOHN GmbH, Ziegelei 1, Germany) and placed into a 50 mL falcon tube. The samples were then transferred to a sterilized mortar and homogenized using a pestle. To facilitate grinding, distilled water was gradually added (20 ml), and resulting solution was moved into a 50 ml calibrated tube. Subsequently, the tube contents were vigorously shaken and left in the dark for

8 minutes. Afterward, 0.4 ml of the clear homogenate was carefully drawn from the 50 mL falcon tube using a 0.5 graduated syringe and transferred into the iExTM CAROTENE. The vials were then placed on a solid surface for approximately five minutes, shaken again, and allowed to stand until two distinct solution phases were visible within the vial (a clear upper phase and a turbid lower phase). At this stage, the absorbance of the upper solution phase was measured at 450 nm using the iCheckTM CAROTENE device. The calculation of TCC was performed as follows:

$$\textbf{Total carotenoid content (TCC)}(\mu\textbf{g/g}) = \frac{\textbf{Vs}}{\textbf{Ws}} \times \textbf{A} \times \textbf{CF}$$

Where V_S represents volume of solution transferred into 50 ml calibrated tube, W_S - weight of the sample (5g), A - absorbance of the iExTM CAROTENE vial content at 450 nm wavelength, and CF denotes the carotenoid factor. To prevent carotenoid degradation due to light exposure, the Total carotenoid content was analysed in a dark environment.

3.5.7 Determination of β-Carotene

β-carotene extraction and analysis was determined by soaking 1 g of composite bread sample in 5 ml of absolute methanol for 2 h at room temperature according to Aremu and Nweze (2017). The activity was carried out in the dark to minimize light degradation effects of β-carotene. The β -carotene layer was separated using hexane through separating funnel. The volume was made up to 10 ml with hexane and then this layer was again passed through sodium sulphonate in a funnel in order to get rid of any moisture from the layer. The absorbance of the layer was measured at 436 nm using hexane as a blank. The beta carotene content was then calculated using the formula below;

$$\beta - \text{Carotene } (\boldsymbol{\mu}\frac{\mathbf{g}}{\mathbf{100g}}) = \frac{\textbf{Absorbance (436nm)}\times\mathbf{V}\times\mathbf{D}\times\mathbf{Y}}{\mathbf{W}} \times 100$$

Where: V is the total volume of extract; D is the dilution factor; W is the sample weight and Y is percentage dry matter content of the sample.

3.5.8 Quantification of Moisture

The moisture was quantified following procedures outlined in AOAC 934.01 as described by Koh et al. (2023) with alterations. A quantity of two grams (2 g) of finely ground composite bread sample was placed onto previously dried and weighed silver dishes. The samples on the dishes were subjected to a 2-hour drying process at 105°C to obtain a consistent weight. Following the drying step, the samples were removed from the oven, allowed to cool within a desiccator at room temperature, and subsequently reweighed:

$$\text{Moisture Content (\%)} = \frac{(W_1 - W_2)}{S_w} \times 100$$

Where W_1 is the weight of the dish and sample before drying, W_2 is the weight of the dish and sample after drying, and S_w is the weight of the sample.

3.6 Determination of dough rheological properties

Dough consistency behavior and water absorption was studied following the official method no. (ICC, 2006). First, the moisture content of the sample was determined as described in section 3.7.1. The amount of water to be added for hydration of the sample was automatically calculated by the Alveoconsistograph (model 2/2, serial no: 181, Chopin Technologies, France) based on the moisture content of the composite sample. Then, the mixer hook was inserted into the 24-mixing bowel of the consistograph followed by 250 g of the sample. Mixing of the composite sample ensued as the water dosing unit of the consistograph started adding water automatically. Mixing proceeded for 5 min and the consistograph simultaneously generated a consistographic curve and accompanying dough rheology properties.

3.7. Determination of physical properties of composite bread

3.7.1 Crumb colour

Crumb colour was determined using a chromameter (CR-400 Series, Konica Minolta, Osaka, Japan) on L*a*b* colour system. The lightness (L* value) was used to indicate product quality.

Crumb of freshly mechanically cut bread surface was used after storage at room temperature for 24hrs. Prior to measuring the crumb colour, the outer crust was eliminated.

3.7.2 Loaf volume and specific volume

The seed displacement techniques outlined in AACC standard method 10–05.01 (AACC, 2000) with appropriate modifications was used to measure the loaf volume, V1 (cm^3). Millet was used in this test. A container was filled with millet grains and levelled using a meter-ruler. The millet seeds were withdrawn from the container into the measuring cylinder and their volume recorded. The bread to be measured was placed in the container. The millet grains were gently poured into the container until the bread was covered and levelled again using a meter-ruler. The volume of the remaining millet grains displaced by the bread was measured using a measuring cylinder and was considered as the volume of the bread expressed in cubic centimeters. Specific volume (cm^3/g) of the composite bread (S_v) was calculated as shown in the equation below: (Chikpah et al., 2021)

$$\mathbf{S_v} = \frac{\mathbf{V_1}}{\mathbf{W_2}}$$

3.7.3 Baking loss

Initial weight (W_1) of the bread and its weight after 2 hours of baking (W_2) were determined using a calibrated digital analytical balance (Radwag WTC 3000 model, Poland) with an accuracy of 0.1 g. The percentage of weight loss during baking was computed using the equation below, as outlined by Chikpah et al. (2021).

$$\textbf{Baking loss } (\%) = \frac{W_1 - W_2}{W_1} \times 100$$

3.7.4 Analysis of crumb texture profile

Texture profile analysis (TPA) was performed on bread crumbs after 2 hours of baking and following a 24-hour storage period using a TVT Texture Analyzer (Perten TVT 6700, S/N 2194483-TVB, Macquarie Park, Australia) to assess attributes like firmness/hardness, springiness, and cohesiveness of the composite bread. The calibrated TVT used employed the double cycle compression mechanism to test the bread crumb properties, fitted with a stainless steel 25mm diameter probe (P- CY255) following the procedure described by (Chikpah et al., 2021) with modifications. The bread loaves were accurately sliced using an electrical slicing machine (Gravity, S/N 4710, South Africa) to give slices of equal thickness. Three slices were compressed at the same time to produce a required thickness of 50mm required for a single test. The compressed slices were placed on the measuring table of the TVT below the probe. The procedure was conducted in the shortest time possible to avoid air contact, which could dry out the test sample thus increasing firmness. This procedure was repeated for each of the 32 runs. Curves where drawn by the analyzer as shown in Appendix. Chewiness was determined using the equation below.

$$\textbf{Chewiness} = \textbf{Hardness} \times \textbf{Cohesiveness} \times \textbf{Springiness}$$

3.7.5 Staling rate analysis

The rate of crumb staling was evaluated following the method outlined by Sahin et al. (2020).

$$\textbf{Staling rate} = \frac{\textbf{Crumb hardness (kg)after 24 h storage} - \textbf{Crumb hardness (kg)after 2 h of baking}}{\textbf{Crumb hardness (kg)after 2 h of baking}}$$

3.8 Sensory evaluation

A panel of 50 untrained consumer panelists were randomly recruited from Kyambogo University to participate in bread sensory analysis after 24hrs of baking. The Inclusion criteria for the panelists was based on good health, non-smoker, non-allergic to wheat gluten, willingness to participate in the evaluation exercise and passion for bread. The different bread samples were assigned three-digit random codes and separately presented to panelists on a white disposable plate along with a cup of portable water to cleanse their mouth between sample tasting. Each panelist was requested to evaluate the bread samples for appearance, flavor/taste, odor/smell, crust colour, crumb colour, texture/consistency and general acceptability using a 9-point Hedonic scale where 1 = dislike very much and 9 = like very much.

Hedonic scale is a measurement tool used to assess and quantify subjective experiences, preferences, or feelings related to pleasure or displeasure. It assumes that participants' preferences exist on a continuum and that their responses can be categorized into like and dislike (Heymann & Lawless, 2013). Thus, the scale has ruler-like and equal-interval properties. The nine-point scale is straightforward to use, and it has been widely studied.

3.9 Statistical analysis

The data was subjected to Response Surface Methodology (RSM) in the Design-Expert V13 software (Stat-Ease, Inc. U.S.A). The relationships among variables and their interactions were determined based on variable coefficients, ANOVA significant levels at $p<0.05$ and percentage contributions (R^2) using the model:

$$\boldsymbol{\hat{y}}=\boldsymbol{\beta_0+\beta_1x_1+\beta_2x_2+\cdots+\beta_{N-1}x_{N-1}+\beta_Nx_N+\beta_{1,2}x_1x_2+\beta_{1,3}x_1x_3+\beta_{2,3}x_2x_3+\cdots+\beta_{(N-1)N}x_{N-1}x_N}$$

Where: $\hat{y}$ is estimated response of study interest; β_0 is average experimental response coefficient; $\beta_1 - \beta_N$ is estimated main effects of factors considered coefficients and $\beta_{1,2} - \beta_{(N-1)}$ the interaction effects of factors considered coefficients. The coefficient of determination, R^2 was used for evaluation of the fitness of the model.

Principal Component Analysis was conducted using XLSTAT 2023 (Version 25.1.140) to investigate the connections between the variables and to distinguish among the different types of bread samples.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1. Rheological properties of composite dough

Table 4.1 illustrates the relationship between proportion of sweet potato puree replacement (X_1), sweet potato variety (X_2), type of sweet potato treatment (X_3), and dough rheological properties of the composite dough.

Table 4. 1. Estimated coefficients for significant model terms of rheological properties of wheat/ unpeeled OFSP puree composite dough

Responses	Significant model	R^2
Prmax	$Y_1 = 1642.58 - 555.92X_1$	0.97
Water absorption	$Y_2 = 50.81 - 2.51X_1$	0.94

X_1- Puree proportion, Y_1- Prmax and Y_2- Water Absorption

Sweet potato puree negatively affected Prmax and Water Absorption. The effect of OFSP variety and processing conditions were not statistically significant. There were no significant interaction effects among the independent variables (proportion of sweet potato puree replacement, sweet potato variety and type of sweet potato treatment) on dough rheological properties.

4.1.1. Prmax

Prmax is defined as maximum overpressure needed to inflate dough bubble, also referred to as dough tenacity (Schopf & Scherf, 2021). Jødal & Larsen (2021) described Prmax as an indication of dough deformation resistance, often known as the degree of softening (DOS). The results of this study indicated a decrease in Prmax as proportion of sweet potato puree in the composite dough increased from 20% to 50%. The results agreed with the findings of Chikpah et al., (2021) who reported a decrease in Prmax with increasing OFSP flour percentage substitution. However, values recorded in this study were lower than those reported by Chikpah et al., (2021); Jødal & Larsen, (2021) ascribed to high moisture content of OFSP. Jødal &

Larsen (2021) agreed to this when they reported that water content of the dough negatively related with Prmax. Subsequent research has reinforced the idea that augmenting the levels of sugar and fiber within flour exerts an influence on the degree of softening, as well as on other rheological attributes like dough development time (DDT) and stability time (ST). Sweet potato roots are high in reducing sugars and fiber compared to wheat flour. This chemical profile coupled with increased fiber content from the peels of unpeeled OFSP in the puree could further be responsible for the decrease in the DOS. As Chikpah et al. (2021) indicated, the decrease in the dough's DOS and thus Prmax can be attributed to the reduction of unbound water due to the presence of increased amounts of sugars and fibers. The unbound water is essential for the development of the gluten network in the dough structure.

4.1.2. Water absorption (WA)

Water absorption (WA) refers to the quantity of water absorbed by flour to attain the desired texture and consistency (Schopf & Scherf, 2021). The study showed a decrease in WA as the proportion of sweet potato puree in composite dough increased from 20% to 50%. The findings aligned with Chikpah et al. (2021), who also noted a reduction in WA of OFSP composite dough as the proportion of sweet potato flour increased from 10% to 60%. The results of the study however disagreed with the findings of Trejo-González et al. (2014) who observed a slight increase in WA of wheat-sweet potato flour composite when sweet potato flour proportions were increased from 10 to 20%. The variance in the results of the researchers could have been as a result of the different structural compositions in the sweet potato varieties that were used to make the flour. Dhaka & Khatkar (2015) reported that the incorporation of higher proportions of sweet potato puree with its high amount of moisture in composite formulations leads to dilution of gluten-forming proteins, moreover these proteins play a role in absorbing a significant quantity of water within their interconnected network, as well as interacting with starch granules. Therefore, less water is required during mixing thus the observed reduction in Water Absorption of wheat/unpeeled OFSP puree

4.2. Physical characteristics of bread made from composite unpeeled OFSP puree

Tables 4.2 and 4.3 demonstrate how ingredients, process conditions and physical properties of the composite bread related in this study. The linear regression coefficients of each factor that affected the physical characteristics of the composite bread and the coefficient of determination (R^2) were used to determine the significance of the effects.

Table 4. 2. Estimated coefficients for significant model terms of physical properties of wheat/ unpeeled OFSP puree composite bread

Independent Variables	Dependent Variables												
	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8	Y_9	Y_{10}	Y_{11}	Y_{12}^{l}	Y_{21}
B_0	57.7	2.55	33.26	452.52	829.3	2.05	11.51	0.39	5.5	0.83	0.66	7.04	42.14
X_1- Sugar	0.15	-0.02			51.68		0.003	0.12**	0.014	-0.002		0.18	0.68*
X_2- Salt	-0.38	0.15*					-0.63**	0.01		-0.001		0.002	
X_3- Fat		-0.05	-0.38**		-5.06			0.01			-0.02***	0.07	
X_4- Yeast		-0.09	0.14*		118.43***		-0.88***	-0.14***	-0.77***		0.001	-0.693***	-0.12
X_5- Puree	-3.83***	2.16***	4.9***	39.68***	-74.54**	-0.47***	-0.53*	-0.08*	0.65**	-0.03***	-0.006	0.691**	1.95***
X_6- Ascorbic acid	0.39	0.03			2.31					-0.009**	0.01**		-0.675**
X_7- Variety	0.92*	-0.27**			15.75		-0.48	-0.001		0.006*		-0.04	-0.47
X_8- Treatment	-2.31**	-0.13			-56.82*		-0.17	-0.07	0.58*	-0.003	-0.0064*	0.5*	0.28
R^2	0.95	0.99	0.85	0.93	0.85	0.36	0.73	0.85	0.88	0.75	0.51	0.93	0.78

Y_1- L*, Y_2- a*, Y_3-b*, Y_4-Weight, Y_5-Volume, Y_6- Specific Volume, Y_7- Baking Loss, Y_8- Staling Rate, Y_9- Firmness, y_{10}- Springiness, Y_{11}- Cohesiveness, Y_{12}- Chewiness, Y_{21}- Moisture. (***) identifies the biggest effects. (**) and (*) mark the second and third most important effects respectively.

Table 4. 3. Percentage Contribution (R^2) of significant model terms of physical properties of wheat/ unpeeled OFSP puree composite bread

Independent Variables	Percentage Contribution												
	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8	Y_9	Y_{10}	Y_{11}	Y_{12}	Y_{21}
X_1- Sugar	0.1**	0.01			6.68**		0.0002	15.52*	0.9	0.02	0.04	1.58	3.38*
X_2- Salt	0.5*	0.41**					12.22*	0.07		0.29	0.70	0.0002	
X_3- Fat			0.48*		0.07			0.08		0.93	23.39***	0.22	
X_4- Yeast			0.07**		39.47***		24.03***	20.92***	25.3***		2.57	22.76***	0.098
X_5- Puree	53.1***	91.3***	81.2***	93.2***	15.4	35.69***	8.78**	5.88**	18.26*	46.85***	3.43	22.62*	27.61***
X_6- Ascorbic acid		0.02			0.01					4.02*	10.92*		3.31**
X_7- Variety		1.47*			0.69		7.23	0.001		1.55**	0.98	0.061	1.6
X_8-Treatment		0.34			8.57*		0.95	4.63	14.14**	0.56	3.77**	11.64**	0.57

Y_1- L*, Y_2- a*, Y_3-b*, Y_4-Weight, Y_5-Volume, Y_6- Specific Volume, Y_7- Baking Loss, Y_8- Staling Rate, Y_9- Firmness, y_{10}- Springiness, Y_{11}- Cohesiveness, Y_{12}- Chewiness, Y_{21}- Moisture. (***) identifies the biggest contribution, (**) and (*) mark the second and third biggest contributions respectively.

4.2.1. Colour of bread

The colour of bread plays a crucial role in determining consumer satisfaction and acceptance. Lightness (L^*), redness (a^*) and yellowness (b^*) of the crumb were significantly affected by different independent variables (Table 4.2 and Table 4.3). Generally, sweet potato puree had the greatest effect on crumb colour. This observation is in agreement with Malavi et al. (2022) who reported a similar effect of sweet potato puree substitution of wheat flour on crumb colour. Increase in sweet potato puree proportions decreased L^* values thus producing composite loaves of bread with darker colour. However, a^* and b* were positively affected. The darker shade of the composite bread's colour might be attributed to the elevated levels of beta-carotene and other pigments, particularly present in the OFSP peels. The contribution of the peels to the dark colour of the composite bread crumb was also observed by Chikpah et al. (2021) who observed that composite bread loaves from unpeeled OFSP flours had darker crumb appearance than those from peeled OFSP ones. Barros et al. (2018) suggested that the colouration of bread is influenced by the specific characteristics of non-wheat flours utilized and chemical transformations such as the Millard reaction occurring during the baking process.

4.2.2. Loaf size-related attributes

Results from the study indicated that weight and specific volume were affected by proportion of potato puree whereas volume and baking loss were affected by yeast. The Proportion of sweet potato puree had the second greatest effect on volume and third on baking loss whereas salt had the second biggest effect on baking loss (Table 4.2 and 4.3). Optimal bread quality is often associated with key attributes such as elevated specific volume (Sahin et al., 2020). Additionally, factors like substantial loaf volume, reduced loaf weight, and minimal baking loss also contribute significantly to desirable bread characteristics

Generally, irrespective of the other independent variables/ingredients that had minor effects on the loaf size properties of the bread, proportion of potato puree had the biggest positive effect on weight and negative effect on specific volume whereas yeast had the greatest positive effect on volume and negative effect on baking loss. Chikpah et al. (2021) observed comparable effects of OFSP flour on specific volume and volume of the studied loaves. Similarly, Edun et al., (2019) noted a reduction in loaf specific volume with the substitution of wheat flour by 10 to 30% OFSP flour. The establishment of the gluten network structure during the bread-making process plays a pivotal role in imparting the viscoelastic properties to the dough. This structure aids in retaining carbon dioxide gas throughout the fermentation and initial baking phases (Barak et al., 2013; Cappelli et al., 2020). During dough mixing, the starch granules within the flour engage with gluten, resulting in the formation of bonds between starch-starch and starch-gluten. These interactions have substantial impact on the elasticity of the dough (Barak et al., 2013). As noted by Zhang et al. (2007), the process of starch gelatinization while baking resulted in elevated dough viscosity, decreased extensibility, and enhanced pressure within enclosed carbon dioxide cells. This heightened pressure could potentially contribute to the disruption of the cell membranes containing CO_2 thus affecting the volume of the bread According to Zhang et al. (2007), it is emphasized that sweet potato starch flour tends to gelatinize at an earlier stage during baking due to its relatively lower gelatinization temperature. This leads to a constrained expansion of the dough, subsequently resulting in diminished loaf volume and specific volume of the bread. Consequently, when wheat is replaced with increasing amounts OFSP puree, it not only reduces gluten content and ability to entrap CO_2, but also a reduces starch gelatinization temperature, thereby contributing to a reduction in the loaf volume and specific volume of the resulting composite bread.

Increase in loaf weight was possibly as a result of increased moisture content of the composite dough mostly contributed by the sweet potato puree. When incorporated into the bread dough, the sweet potato particles can trap and retain water more effectively than wheat flour alone. Also, the hydration of starch granules and fiber components in sweet potato contributes to the increased water retention in the composite bread (Omoba et al., 2020). As a result, less moisture was lost during the baking process giving a heavier loaf.

The enhancement in loaf volume as a result of yeast can be ascribed to the elevated sugar content resulting from increased proportions of sweet potato puree. This, in turn, leads to heightened production of CO_2 and ethanol, which are byproducts of yeast fermentation and contribute to the increase in bread loaf volume (Timmermans et al., 2022).

During baking, dough is transformed into bread through moisture loss, changes in structure and increased volume. Baking loss is characterized by loss of loaf mass during baking as a result of losses of moisture and starch retrogradation (reassociation of gelatinized starch). Loss of moisture produces bread with a low weight and most likely a dry crust, leading to disadvantageous effects on bread freshness thus staleness. Olagunju (2019) reported that the most significant carbohydrates (reducing sugars) from flour influencing the loaf properties are glucose, fructose and sucrose. During starch gelatinization these sugars are sequentially broken down by yeast assisted by amylase enzyme that is fortified in the wheat flour (used during the study). The role of amylase in the fermentation process is to continuously generate new glucose and maltose from the reducing sugars available in the dough until it’s depleted at the recommended baking temperatures and times. As a result of increased reducing sugars contributed by the OFSP puree, not all the sugars are degraded during baking hence increasing their water holding capabilities after baking (Omoba et al., 2020). Therefore, increasing the yeast levels during the baking of wheat/OFSP puree reduces the baking loss properties of the bread thus desirable freshness of the bread after baking. Sweet potato flours have been recognized as valuable dough improvers in baking, as noted by Rosell et al. (2001, 2007) and

Mandala et al. (2007). They contribute to enhanced bread weight, diminished baking losses, delayed staling, and improved water retention properties. These attributes highlight their significant impact in baking. These capabilities were greatly enhanced by the increased fiber content in the potato which is more in the unpeeled OFSP puree (Omoba et al., 2020).

The moisture content plays a crucial role in determining the physical, sensory, and microbial characteristics of bread, making it an essential attribute of food quality. The results showed a positive relationship between increased proportion of OFSP puree and moisture content. Moisture content also varied significantly with increase in sugar levels with a minor but significant decrease with increase in ascorbic acid levels. The findings were in agreement with the results shown by Malavi et al. (2022) who reported a significant increase in the moisture content of 50% OFSP puree bread as compared to 100% wheat flour white bread. A similar result was reported by Bonsi et al., (2016) who observed that bread with OFSP puree had 17% more moisture than 100% wheat bread. The increased moisture content observed in the composite bread with unpeeled OFSP puree can be ascribed to the robust water-binding ability of sweet potato starch, facilitated by the comparatively weaker molecular forces among its starch granules, as elucidated in Srivastava et al. (2012) study. This phenomenon provides an expanded molecular surface for water binding during starch gelatinization, resulting in enhanced moisture retention within the composite bread. This aligns with findings from Iheagwara (2013) and Kotoki & Deka (2010). Increased sugar levels contribute to the enhanced water binding capabilities exhibited by OFSP puree thus increased moisture content of the composite bread. The minor effect of ascorbic acid on moisture content cannot be ignored in this study because it has an impact on the staling rate and palatability of the bread. This could be as a result of the effect of ascorbic acid on the water redistribution in the bread during the storage (Kerch et al., 2012).

4.2.3. Textural properties

Yeast, potato puree proportion, and fat content exerted a great influence on the crumb textural properties, including firmness, springiness, cohesiveness, and chewiness. Puree negatively affected springiness, yeast had a negative effect on firmness and chewiness whereas cohesiveness was negatively affected by fat.

Textural attributes play a crucial role in assessing the bread's freshness and have a significant impact on consumer acceptability (Tsai et al., 2012). Crumb springiness represents the recovery of the bread after compression, which can be used to separate soft, soggy bread from soft but resilient bread (Hager et al., 2012). Increasing proportions of sweet potato puree from 20-50% produced a soft but less resilient bread. This result is in agreement with Chikpah et al. (2021) who too observed a negative effect with increased proportions of potato flours on springiness. The decrease in springiness might be related to the partial dehydration and dilution of gluten in wheat flours as their levels reduced with increase in potato puree proportions as well as insufficient starch swelling and gelatinization during baking (Azadfar et al., 2023).

Crumb cohesiveness represents the susceptibility to fracture or crumble and low cohesiveness has adverse effect on consumers' acceptance of bread (Xu et al., 2019). Bread cohesiveness decreased with increase in levels of fat thus producing loaves which could easily crumble. This decrease in bread cohesiveness is in agreement with Mancebo et al. (2017) who illustrated in his study that addition of oil to levels up to 30% during the production of wheat-rice bread reduced the cohesiveness and springiness of the composite bread. This might be attributed to the weakening of gluten structure by fat. Fats play a role in preventing the development of a gluten network in dough as noted by (Ooms & Delcour, 2019).

The process of bread crumb staling primarily involves the firming of the crumb. After a 24-hour storage period, the findings indicated a predominant impact, with yeast being a significant contributor to this effect. Staling rate, firmness and chewiness decreased with increased yeast levels. The decrease in staling rate, firmness and chewiness as a result of increased yeast levels might be attributed to increased quantity of enzymes in dough during fermentation (Martínez & Gómez, 2017). The addition of starch-degrading enzymes has been found to retard the firming and staling rate by altering the structure of starch and soluble carbohydrate profile (Hug-Iten et al., 2003).

4.3 Nutritional composition of composite wheat/unpeeled OFSP puree bread

Table 4.3 shows the results of nutrient composition of the wheat/OFSP composite bread and coefficient of determination R^2.

Table 4. 4. Estimated coefficients for significant model terms of Nutrient Composition of wheat/ unpeeled OFSP puree composite bread

Independent Variables	Dependent Variables							
	Y_{13}	Y_{14}	Y_{15}	Y_{16}	Y_{17}	Y_{18}	Y_{19}	Y_{20}
B_0	51.32	9.76	5.59	10.98	14.72	13.03	0.38	4.95
X_1- Sugar	-0.01	-0.01	0.08	0.19*	-0.06	0.15	0.01	-0.02
X_2- Salt	0.01	0.08	0.07	0.09	0.04	0.16	0.01	0.01
X_3- Fat	0.04	0.2		0.18	0.21			0.07
X_4- Yeast	-0.05	-0.26	-0.15*		-0.22	-0.33	-0.02*	-0.07
X_5- Puree	0.4***	2.04***	0.68***	-0.03	2.22***	1.69***	0.06***	0.75***
X_6- Ascorbic acid	0.01	0.01	-0.005	-0.41**	0.04	-0.02	-0.003	0.01
X_7- Variety	-0.06*	-0.3*	-0.15	0.87***	-0.3*	-0.34*	-0.01	-0.11*
X_8- Treatment	0.12**	0.67**	0.41**	-0.14	0.63**	0.83**	0.05**	0.21**
R^2- Fit of regression	0.98	0.98	0.98	0.95	0.93	0.99	0.96	0.95

Y_{13}- TCC, Y_{14}- β-carotene, Y_{15}- Vitamin A, Y_{16}- Crude fiber, Y_{17}- Reducing sugar, Y_{18}- Protein, Y_{19}- AML: AMP, Y_{20}- Starch.
(***) identifies the biggest effects. (**) and (*) mark the second and third most important effects respectively

Table 4. 5. Percentage Contribution (R^2) of significant model terms of Nutritional Composition of wheat/ unpeeled OFSP puree composite bread

Independent Variables	Percentage contributions							
	Y_{13}	Y_{14}	Y_{15}	Y_{16}	Y_{17}	Y_{18}	Y_{19}	Y_{20}
X_1- Sugar	0.03	0.003	0.71	1.15**	0.06	0.50	0.73	0.06
X_2- Salt	0.09	0.14	0.63	0.23	0.03	0.56	0.6	0.03
X_3- Fat	0.96	1.08		1.08	0.75			0.74
X_4- Yeast	1.09	1.29	2.78**		0.79	2.39	2.66**	0.79
X_5- Puree	82.05***	79.75***	56.44***	0.03	84.2***	64.53***	42.66***	84.2***
X_6- Ascorbic acid	0.01	0.003	0.003	5.2*	0.03	0.008	0.11	0.03
X_7- Variety	1.91**	2.21**	2.61	25.02***	1.68**	2.55**	2.39	1.67**
X_8- Treatment	7.66*	8.54*	20.0*	0.64	6.86*	15.53*	29.1*	6.86*

Y_{13}- TCC, Y_{14}- β-carotene, Y_{15}- Vitamin A, Y_{16}- Crude fiber, Y_{17}- Reducing sugar, Y_{18}- Protein, Y_{19}- (Amylose: Amylopectin) AML: AMP, Y_{20}- Starch

The results indicated predominant positive effect ($p<0.05$) of proportion of potato puree on composite bread starch, Total Carotenoid Content (TCC), β-carotene, vitamin A, reducing sugar, Amylose-amylopectin ratio (AML: AMP) and protein with variety of the OFSP positively affecting crude fiber content of the composite bread. Generally, the study demonstrated that replacing wheat with puree resulted in enhancement of the nutritional profile within the composite bread. The results are in agreement with Malavi et al. (2022) who concluded that partial substitution of wheat flour with OPSP puree had a profound effect on the nutritional properties of composite bread.

Carotenoids are a class of naturally occurring pigments synthesized by plants, algae and photosynthetic bacteria. They are responsible for the orange colour in the OFSP and the more their content, the deeper the colour. OFSP exhibit the highest carotenoid content when compared to other fruits and vegetables (Stathers et al., 2018). As expected, partial substitution of wheat flour with unpeeled OFSP puree increased the Total Carotenoid Content (TCC) of the bread. This is as a result of the varieties (NKB 135 and NASPOT 13O) used in the study that

were biotechnologically fortified to increase vitamin A consumption in the target populations. Important to observe however was the positive significant effect of treatment on TCC. Ejiofor & Onyeso, (2019) in their study indicated a minor decrease in the carotenoid content of OFSP after steaming as compared to other processing methods like frying. Increase in the carotenoid content was also attributed to OFSP puree that was prepared from fresh unpasteurized tubers. It’s also possible that not peeling the OFSP tubers retained some carotenoids that contributed to the positive effect. This could have been contributed to by the puree that was prepared from unpeeled fresh OFSP (Stathers et al. 2018). Increase in TCC expectedly increased β- carotene levels in the bread as the dominant carotene in NKB 135 and NASPOT 13O as compared to the cis-isomers and other carotenoids in OFSP (Malavi et al., 2022a). Vitamin A, being a retinol activity equivalent (RAE) of β- carotene on consumption, increased with increase in puree β-carotene levels. The results were similar to the previously reported study findings by Nzamwita et al. (2017) and Low & van Jaarsveld (2008) who illustrated that increasing the proportion of potato flour in composite wheat/OFSP bread increased the β-carotene amount and thus an increase in the recommended dietary allowance of vitamin A amongst the different age groups.

The starch content, reducing sugars and protein were affected by increased proportions of potato puree. The increase in starch and reducing sugars as a result of increased percentage puree proportions was much higher than the increase in protein. This was in agreement with Malavi et al. (2022), whose values were higher compared to Greene & Bovell-Benjamin (2004); Kotoki & Deka (2010). A significant concentration of carbohydrates in the form of starch is advantageous as it promotes gelatinization and the development of desirable bread texture. Moreover, from a nutritional perspective, the introduction of OFSP in composite bread has been found to substantially fulfill daily nutritional requirements of targeted consumer group.

The protein content of the composite bread slightly increased with an increase in the proportion of potato puree. This finding was similarly reported by Malavi et al., (2022) who observed a slight increase in the protein content of wheat/OFSP flour composite bread. Conversely, the protein content observed in this research exhibited a notable increase in comparison to the results presented by Malavi et al. (2022). Moreover, in the study of Elkatry et al., (2023) , protein content was considered a minor proportion of OFSP flour or OFSP peel flour thus insignificant contribution to the composite bread. This anomaly could possibly be as a result of protein interaction and binding. The proteins from wheat and sweet potatoes could potentially interact and form complexes that lead to increased protein content (Ohimain, 2014).

These complexes might not be as easily digestible as free-form proteins during the baking process, but they still contribute to the total protein content of the bread.

Change in crude fiber content of the composite bread varied from variety 1 (NATSPORT 13O) to variety 2 (NKB 135). The increase however was not steep implying that there was not a major difference in the crude fiber content of these varieties. However, there was a significant increase in the fiber content of the composite bread in the current study. In comparison with crude fiber content in composite breads from other wheat flour substitution, Malavi et al., (2022) observed higher crude fiber content in OFSP puree bread than 100% wheat flour bread, maize and OFSP flour composite bread. The variation in fiber content within the bread, as noted by Malavi et al. (2022), can be attributed to disparities in wheat flour substitutes, encompassing varietal and fiber compositional distinctions. The elevation in crude fiber content was further accentuated by the substantial fiber content inherent in the included peels present in the puree.

The Amylose-Amylopectin ratio was positively affected by the proportion of puree. During the fermentation process, added water during dough mixing assists the hydrolysis of starch (amylose and amylopectin) molecules into smaller sugar molecules that are easily broken down by yeast forming gas and ethanol. During this process, amylose molecules undergo faster hydrolysis because of the linear structure making them easier to hydrolyze. Just like wheat flour, sweet potato contains more amylose molecules than amylopectin (Edun et al., 2019). The increased proportion of OFSP puree in the composite dough escalated the amylose content hence increase of the AML: AMP ratio. This occurrence further explains the reduction in composite bread firmness when the puree used in the composite bread was made from pasteurized tubers than fresh tubers. High temperature treatment (Pasteurization) of the OFSP tubers reduces the branching frequencies of the amylopectin thus exposing them for hydrolysis during fermentation (Jiang et al., 2003). Pasteurization treatment of OFSP tuber therefore yielded bread loaves of acceptable texture due to its effect on starch hydrolysis as compared OFSP tubers that were unpasteurized (fresh).

4.4 Sensory properties of composite wheat/unpeeled OFSP puree bread

Table 4.6 shows the estimated coefficients of linear model terms of each factor that affected the sensory properties of the composite bread and the coefficient of determination (R^2). Results from the study indicated that proportion of potato puree exhibited the greatest effect as compared to other ingredients. It had negative effects on flavor, aroma and general acceptability of the composite bread. Yeast had a positive effect on crust colour whereas fat and salt had negative effects on appearance and crumb colour respectively moreover, treatment had the greatest negative effect on texture among all the ingredients. In comparison however, sensory crumb colour was negatively affected by salt, whereas instrumental crumb colour (L^*, a^* and b^*) was positively affected by proportion of potato puree. Important to observe is that whereas treatment had the greatest effect on sensory texture, yeast had the greatest negative effect on instrumental texture (firmness and chewiness). Proportion of potato puree and fat had negative effects on springiness and cohesiveness respectively.

Irrespective of the effects by the different ingredients on the different sensory attributes, the general acceptability of the composite bread was significantly ($p<0.05$) influenced by proportion of potato puree. Panelists preferred loaves that had 20% OFSP puree over the loaves that had 50% OFSP puree. The findings from this study contrasted with those presented by Malavi et al. (2022), who indicated a preference for composite bread containing 50% OFSP puree. Assessment of the effects of puree on other sensory properties (appearance, crumb colour, flavor and texture) indicated negative effects. However, bread with higher levels of OFSP puree (50%) exhibited better aroma scores. This observation was in agreement with the observations made by (Malavi et al., 2022a). It's important to note the adverse impact of the treatment on the bread's texture. Panelists preferred loaves of bread that were prepared from pasteurized tubers of unpeeled OFSP over the loaves that were prepared from unpasteurized/fresh unpeeled OFSP tubers. This is most possibly because during pasteurization of the OFSP tubers, starch in the sweet potato is gelatinized increasing the substrate (in the composite dough) accessibility for enzymatic and chemical reactions during fermentation and baking. Starch gelatinization has a profound effect on the water holding capacity which this study has found to be a positive attribute of OFSP composite dough thus soft bread texture (tender and less chewy) (Truong & Avula, 2010). Cheng et al. (2022) further suggested that starch hydrolysis affected the crumb structure by weakening the starch matrix that supports gas cell formation during fermentation and baking. This can result into a finer and more uniform crumb texture.

Table 4. 6. Estimated coefficients for significant model terms of sensory properties of wheat/ unpeeled OFSP puree composite bread

Variables	Responses						
	Y_{22}	Y_{23}	Y_{24}	Y_{25}	Y_{26}	Y_{27}	Y_{28}
B_0	7.21	6.92	6.71	6.04	6.61	5.8	6.54
X_1- Sugar	-0.09*	0.09**	0.005	0.18*	-0.07	0.11*	0.07**
X_2- Salt		-0.3***	-0.11*	-0.1	0.08		
X_3- Fat	-0.18***	0.02	0.14**	-0.001	-0.13**		
X_4- Yeast			0.25***	0.08	0.07	-0.19**	0.04*
X_5- Puree	-0.12**	-0.07*	-0.06	-0.45***	-0.1*	-0.21***	-0.3***
X_6- Ascorbic acid	-0.04	0.05	0.05	0.04	0.001		
X_7- Variety		0.05	-0.03	0.19**	0.03		
X_8- Treatment		0.03		0.17	-0.23***	0.08	
R^2- Fit of regression	0.6	0.89	0.87	0.99	0.92	0.69	0.52

Y_{22}=Appearance, Y_{23}=crumb colour, Y_{24}= crust colour, Y_{25}=flavour, Y_{26}=texture Y_{27}=aroma and Y_{28}=general acceptability. (***) identifies the biggest effects, (**) and (*) mark the second and third most important effects respectively

Table 4. 7. Percentage Contribution of significant model terms of sensory properties of wheat/ unpeeled OFSP puree composite bread

Variables	Percentage Contribution						
	Y_{22}	Y_{23}	Y_{24}	Y_{25}	Y_{26}	Y_{27}	Y_{28}
X_1- Sugar	2.28**	1.7*	0.005	4.73**	1.35	5.12**	2.11*
X_2- Salt		20.34***	2.76**	1.43	2.12**		
X_3- Fat	10.08***	0.13	4.42*	0.003	4.79*		
X_4- Yeast			14.34***	0.096	1.67	15.4*	0.6**
X_5- Puree	4.18*	1.09**	0.82	30.13***	3.1	19.43***	34.98***
X_6- Ascorbic acid	0.57	0.58		0.25	0.0002		
X_7- Variety			0.55	5.51*	0.35		
X_8- Treatment		0.45	0.23	4.09	15.18***	2.53	

Y_{22}=Appearance, Y_{23}=crumb colour, Y_{24}= crust colour, Y_{25}=flavour, Y_{26}=texture Y_{27}=aroma and Y_{28}=general acceptability. (***) identifies the biggest effects, (**) and (*) mark the second and third most important effects respectively

4.5. Principle Component Analysis (PCA)

Fig 4.1 shows the correlations loading among physical, chemical and sensory properties of the wheat flour-unpeeled OFSP bread to identify the most important ingredients that affect bread quality.

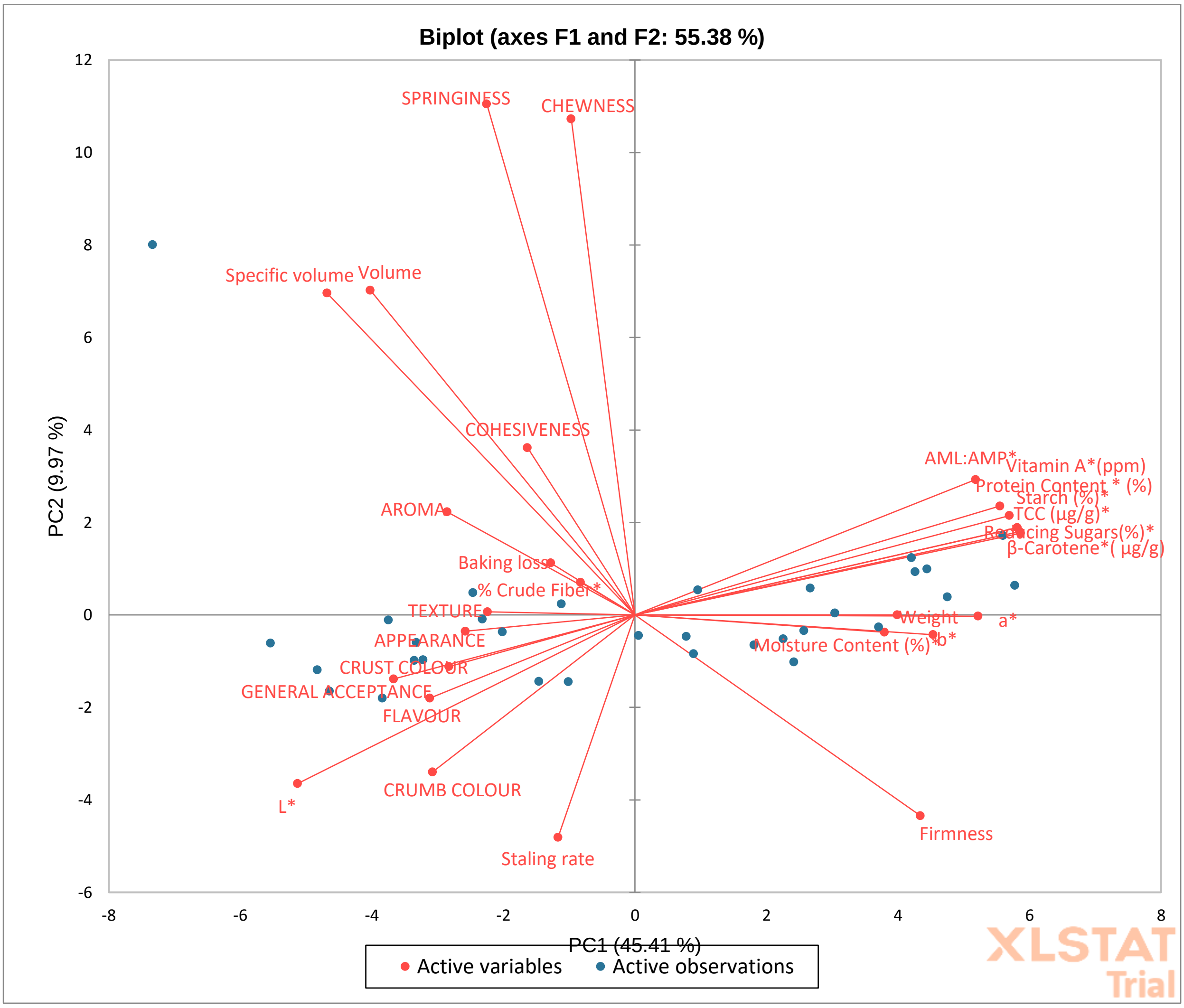

Figure 4. 1. correlation loading plot from principle component analysis of wheat-unpeeled OFSP bread physical and sensory attributes. L*=lightness, a*=redness, b*=yellowness, figures 1 to 32 represent different runs

The first two principle components (PC1 and PC2) accounted for 55.38% of the variation (45.41% and 9.97% respectively). The third principle component (PC3) accounted for 8.88% and the fourth principle component (PC4) accounted for 7.244%. PC1 was characterized by instrumental colour measurements (a*, b*), loaf size related parameters (weight, moisture content), instrumental texture (firmness), and nutrient composition (starch, TCC, beta-carotene, vitamin A, reducing sugar, protein, AML: AMP) on positive axis while L*, volume, specific volume, baking loss, appearance, crumb colour, crust colour, flavour, texture, aroma, general acceptance and crude fiber on negative axis. PC2 was characterized by instrumental textural properties (springiness, cohesiveness, chewiness on positive axis while staling rate on negative axis).

Sensory characteristics: appearance, aroma, crust colour, crumb colour, texture and flavour had a positive correlation with general acceptability of the composite bread. Physical attributes that is staling rate, crumb L*, baking loss, specific volume, volume positively correlated with general acceptability. This implies that consumers preferred bread that had high volume. Consumers are always attracted to bread with high volume believing that it has more substance for the same price (Shittu et al., 2007). Firmness, springiness, loaf weight and chewiness had negative relationships with general acceptability. This implies that consumers preferred bread which is less firm, less chewy, and less springy. Crumb firmness is one of the most important attributes in baked goods as it is associated with consumer's perception of freshness (Ahlborn et al., 2005). Most consumers prefer bread with soft crumb (Maurice et al., 2022). Nutritional composition: AML: AMP, vitamin A, TCC, starch, reducing sugar, beta-carotene had negative correlations with general acceptability while crude fiber had positive relationship. Embracing the inclusion of bread made from unpeeled OFSP puree presents promising benefits, offering a valuable source of dietary fiber crucial for enhancing human health. This significance is underscored by the insights of Yang et al. (2017).

Baking loss, specific volume, volume, springiness, chewiness, cohesiveness is positively correlated but negatively correlated to moisture content, weight, firmness and staling rate. Weight of the composite bread can be explained by the moisture content of the bread. Similarly, the baking loss of the composite bread can be explained with moisture content of the bread. These results implied that OFSP-wheat breads with higher specific volume, baking loss, and volume had high springiness, cohesiveness but less firm, lighter in colour with low moisture. The observations were in agreement with Villarino et al. (2015) who worked on Australian sweet lupin.

Crumb L* was negatively related; while crumb a* and crumb b* were positively correlated with AML: AMP, vitamin A, protein, starch, reducing sugar, TCC, beta carotene. Crumb L* was positively correlated with crude fiber. The negative correlation of crumb L* and positive correlation of a* and b* with AML: AMP, vitamin A, protein, starch, reducing sugar, TCC, beta carotene may be as a result of beta carotene and TCC which contribute to the yellow colour, Millard reaction which is influenced by reaction between amino acid and reducing sugar and participation of sugar (Malavi et al., 2022) and starch in caramelization during baking (Lim et al., 2011). Therefore, bread with higher proportion of sweet potato puree was less preferred because of its dark colour as compared to bread of less proportion of sweet potato puree.

4.6. Overall ranking of experimental effects

Table 4.8 indicates the ranking of the effects of the individual independent variables on the quality of the bread. Overall ranking was calculated based on average coefficient of determination/percentage contribution (R^2) of each independent variable as shown in the equation 10.

Table 4.8. Ranking of different independent variables according to their importance.

Ingredients	Coefficient of determination (%)
Puree	38.96
Yeast	8.96
Treatment	7.4
Variety	3.16
Fat	3.08
Salt	2.27
Sugar	1.95
Ascorbic acid	1.47

$$\text{Overall effect} \quad = \quad \frac{\sum \boldsymbol{R^2}}{\boldsymbol{N}}$$

Where R^2 = overall Coefficient of determination/percentage contribution of an independent variable, N=number of experimental responses/dependent variables

As discussed in the previous chapters, it was evident from the study that proportion of puree had the greatest effect followed by yeast and treatment on the overall rheological behavior of the composite dough and composite bread quality. The observed effects attributed to by the incorporation of puree can be attributed to the interplay of starch and fiber within the puree. These components play a role in modifying water absorption capacity, dough rheology, and the overall bread structure. Elevated substitution levels of puree might have induced a shift in the equilibrium between starch and fiber, consequently impacting dough development and the texture of the crumb thus a profound effect on the composite bread quality and acceptability.

The influence of yeast fermentation in generating carbon dioxide and ethanol is crucial for the volume and texture of bread. The presence of fermentable sugars is essential for yeast activity and subsequent gas production during fermentation. Changes in the content of sweet potato puree within the composite bread formulation can potentially alter the availability of these fermentable sugars. From a rheological perspective, variations in fermentable sugar availability can impact the dough development process. Alterations in the concentration of fermentable sugars may influence the kinetics of gas production, affecting the dough's ability to rise and develop the desired structure. Hence, maintaining a delicate equilibrium between the content of sweet potato puree and yeast activity is crucial to ensure optimal gas production, facilitate proper dough development, and uphold the desired quality attributes of the resulting sweet potato composite bread.

As previously discussed, the significant influence of treatment (pasteurized and unpasteurized/freshness) on the rheological properties of the composite dough can be linked to its impact on naturally occurring enzymes that have a role in various biochemical processes. Similarly, the application of heat can induce starch gelatinization, protein denaturation, and modifications in the overall structure of the puree. These alterations in structure can consequently impact how various components of the sweet potato interact with other ingredients upon their incorporation into the bread dough. As a consequence, rheological characteristics like dough elasticity, extensibility, and viscosity can be altered by these transformations. Subsequently, shifts in dough behavior have the potential to affect the ultimate volume, texture, and crumb attributes of the bread.

In the context of composite bread quality, the combination of enzymatic and structural adjustments due to pasteurization can collectively impact the comprehensive quality traits of the sweet potato composite bread. These modifications can exert an influence on the characteristics of the dough, the efficiency of fermentation, and the sensory attributes including texture, volume, and flavor of the composite OFSP bread.

Careful consideration and optimization of the proportion of puree, yeast content and pasteurization conditions are necessary to strike a balance between desired composite bread attributes and acceptability in the context of sweet potato composite bread production.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusion

From the study, the hierarchy of the effects of independent variables on dependent variables was categorized as: Proportion of puree>yeast>treatment>variety>fat>salt>sugar>ascorbic acid. Proportion of unpeeled OFSP puree significantly reduced Prmax and water absorption. It exhibited a significant negative effect on crumb colour, specific volume, general acceptability and had a positive effect on weight, moisture content, β-carotene content and vitamin A content. Yeast positively affected volume and crust colour with negative effect on baking loss, staling rate and firmness. Treatment of OFSP (pasteurized and unpasteurized/fresh) negatively affected texture. Variety NASPOT13O had a negative effect on crude fiber whereas NKB135 exhibited a positive effect. Fat negatively affected cohesiveness. Ascorbic acid had the least effects on the study wheat/OFSP composite bread quality. Principle Component Analysis indicated a negative correlation between nutritional and sensory properties except crude fiber that positively correlated with sensory properties. A positive correlation was also observed between textural properties and sensory properties except firmness, moisture content and weight that inversely correlated with sensory properties. There was high correlation between physical and sensory properties of bread. The study concluded that the most significant among the selected ingredients that affected quality of wheat/unpeeled OFSP bread were proportion of puree, yeast and fat. The study also concluded that treatment and variety had significant effects on the quality of the composite bread.

5.2. Recommendation

Physical, nutritional and sensory analyses showed that substitution of wheat flour with 20% OFSP puree yielded acceptable breads. However, further research can be undertaken to optimize the ingredients and processing conditions with the greatest effects on composite bread quality.

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APPENDICES

APPENDIX 1:

LINEAR REGRESSION MODELS

1.1. Linear regression equations and regression coefficient, R^2 for physical properties

Responses	**Significant models**	**R^2**
Lightness L*	$Y_1 = 57.7 + 0.15X_1 - 0.38X_2 - 3.83X_5 + 0.39X_6 + 0.92X_7 - 2.31X_8 + 0.81X_1X_8 - 0.72X_2X_5 - 0.10X_2X_8 - 1.13X_6X_8 + 1.01X_1X_2X_8$	0.95
Redness a*	$Y_2 = 2.55 - 0.02X_1 + 0.15X_2 - 0.05X_3 - 0.09X_4 + 2.16X_5 + 0.03X_6 - 0.27X_7 - 0.13X_8 + 0.02X_1X_3 - 0.05X_1X_4 - 0.2X_1X_6 - 0.23X_2X_8 - 0.11X_3X_4 + 0.20X_5X_6 - 0.19X_4X_6 - 0.24X_6X_8 - 0.08X_1X_3X_4$	0.99
Yellowness b*	$Y_3 = 33.26 - 0.38X_3 + 0.14X_4 + 4.9X_5 - 0.91X_3X_4$	0.85
Weight (g)	$Y_4 = 452.52 + 39.68X_5$	0.93
Volume (cm)	$Y_5 = 829.31 + 51.68X_1 - 5.06X_3 + 118.43X_4 - 74.54X_5 + 2.31X_6 + 15.79X_7 - 56.82X_8 + 30.57X_1X_3 + 44.18X_1X_6 - 51.19X_1X_8 - 26.68X_3X_8 - 32.31X_5X_7$	0.85
Specific volume (cm/g)	$Y_6 = 2.05 - 0.47X_5$	0.36
Baking loss (%)	$Y_7 = 11.85 - 0.97X_2 - 1.22X_4$	0.75
Staling rate	$Y_8 = 0.39 + 0.12X_1 + 0.01X_2 + 0.01X_3 - 0.14X_4 - 0.08X_5 - 0.001X_7 - 0.07X_8 + 0.12X_1X_2 - 0.07X_1X_4 - 0.07X_3X_5 + 0.09X_4X_8 + 0.06X_5X_7$	0.85
Firmness (N)	$Y_9 = 5.5 + 0.14X_1 - 0.77X_4 + 0.65X_5 + 0.58X_8 - 0.51X_1X_4 + 0.65X_1X_8$	0.88
springiness	$Y_{10} = 0.83 - 0.002X_1 - 0.001X_2 - 0.03X_5 + 0.004X_7 - 0.005X_8 - 0.002X_1X_2 - 0.003X_1X_8 - 0.007X_2X_8 - 0.01X_5X_7 - 0.01X_1X_2X_8$	0.75
Cohesiveness	$Y_{11} = 0.66 - 0.02X_3 + 0.001X_4 - 0.01X_5 - 0.01X_4X_5$	0.51
chewiness	$Y_{12} = 7.04 + 0.18X_1 + 0.002X_2 + 0.07X_3 - 0.69X_4 + 0.69X_5 - 0.04X_7 + 0.50X_8 - 0.21X_1X_3 - 0.43X_1X_4 + 0.57X_1X_8 - 0.23X_2X_8 - 0.23X_3X_5 - 0.21X_7X_8$	0.93

1.2. Linear regression equations and regression coefficient, R^2 for nutritional properties

Responses	Significant model	R^2
TCC	$Y_{13} = 51.32 - 0.01X_1 + 0.01X_2 + 0.04X_3 - 0.05X_5 + 0.40X_5 + 0.01X_6 - 0.06X_7 + 0.12X_8 - 0.02X_1X_2 - 0.03X_1X_8 + 0.02X_2X_8 + 0.05X_5X_8 - 0.05X_6X_8 - 0.04X_1X_2X_8$	0.98
β-carotene	$Y_{14} = 9.76 - 0.01X_1 + 0.08X_2 + 0.2X_3 - 0.26X_4 + 2.04X_5 + 0.01X_6 - 0.3X_7 + 0.67X_8 - 0.1X_1X_2 - 0.15X_1X_8 + 0.10X_2X_8 + 0.28X_5X_8 - 0.30X_6X_8 - 0.23X_1X_2X_8$	0.98
Vitamin A	$Y_{15} = 5.59 + 0.08X_1 + 0.07X_2 - 0.15X_4 + 0.68X_5 - 0.005X_6 - 0.15X_7 + 0.41X_8 - 0.02X_1X_2 - 0.07X_1X_8 + 0.03X_2X_8 + 0.18X_5X_8 - 0.21X_6X_8 - 0.11X_1X_2X_8$	0.95
Crude fibre	$Y_{16} = 10.98 + 0.19X_1 + 0.09X_2 + 0.18X_3 - 0.03X_5 - 0.41X_6 + 0.89X_7 - 0.14X_8 - 0.66X_1X_3 - 0.36X_1X_6 - 0.32X_2X_5 + 0.38X_2X_8 + 0.49X_3X_5 - 0.49X_3X_7 - 0.41X_3X_8 + 0.45X_5X_6 + 0.46X_7X_8$	0.93
Reducing sugar	$Y_{17} = 14.72 - 0.06X_1 + 0.04X_2 + 0.21X_3 - 0.22X_4 + 2.22X_5 + 0.04X_6 - 0.3X_7 + 0.63X_8 - 0.12X_1X_2 - 0.14X_1X_8 + 0.09X_2X_8 + 0.32X_5X_8 - 0.22X_6X_8 - 0.22X_1X_2X_8$	0.99
Protein	$Y_{18} = 13.03 + 0.15X_1 + 0.16X_2 - 0.33X_4 + 1.69X_5 - 0.02X_6 - 0.34X_7 + 0.83X_8 - 0.06X_1X_2 - 0.16X_1X_8 + 0.06X_2X_8 + 0.36X_5X_8 - 0.45X_6X_8 - 0.25X_1X_2X_8$	0.96
AML: AMP	$Y_{19} = 0.38 + 0.01X_1 + 0.01X_2 - 0.02X_4 + 0.06X_5 - 0.003X_6 - 0.01X_7 + 0.05X_8 - 0.004X_1X_2 - 0.01X_1X_8 + 0.004X_2X_8 + 0.03X_5X_8 - 0.02X_6X_8 - 0.01X_1X_2X_8$	0.95
Starch	$Y_{20} = 4.95 - 0.02X_1 + 0.01X_2 + 0.07X_3 - 0.07X_4 + 0.75X_5 + 0.01X_6 - 0.11X_7 + 0.21X_8 - 0.04X_1X_2 - 0.05X_1X_8 + 0.03X_2X_8 + 0.11X_5X_8 - 0.07X_6X_8 - 0.07X_1X_2X_8$	0.99
Moisture	$Y_{21} = 42.14 + 0.68X_1 - 0.12X_4 + 1.95X_5 - 0.68X_6 - 0.47X_7 + 0.28X_8 + 1.16X_1X_4 + 1.78X_5X_7 - 1.08X_6X_8$	0.78

1.3. Linear regression equations and regression coefficient, R^2 for sensory properties

Responses	**Significant models**	$\mathbf{R^2}$
Appearance	$Y_{22} = 7.21 - 0.09X_1 - 0.18X_3 - 0.12X_5 - 0.04X_6 + 0.24X_1X_5 + 0.26X_5X_6$	0.60
Crumb colour	$Y_{23} = 6.92 + 0.09X_1 - 0.30X_2 + 0.02X_3 - 0.07X_5 + 0.05X_6 - 0.05X_8 + 0.11X_1X_2 - 0.17X_1X_3 - 0.01X_1X_5 - 0.03X_2X_5 - 0.27X_3X_5 + 0.34X_3X_7 - 0.20X_5X_6 - 0.18X_1X_2X_5$	0.89
Crust colour	$Y_{24} = 6.71 + 0.005X_1 - 0.11X_2 + 0.14X_3 + 0.25X_4 - 0.06X_5 + 0.05X_7 - 0.03X_8 + 0.13X_1X_2 - 0.29X_1X_5 + 0.0001X_2X_5 - 0.24X_3X_4 + 0.27X_4X_5 - 0.14X_7X_8 - 0.16X_1X_2X_5$	0.87
Flavour	$Y_{25} = 6.04 + 0.18X_1 - 0.10X_2 - 0.001X_3 + 0.08X_4 - 0.45X_5 - 0.04X_6 - 0.19X_7 - 0.17X_8 + 0.01X_1X_2 - 0.08X_1X_3 + 0.13X_1X_5 + 0.05X_1X_6 - 0.15X_1X_8 + 0.17X_2X_5 + 0.15X_2X_8 - 0.14X_3X_4 + 0.02X_3X_5 + 0.13X_3X_8 - 0.07X_4X_5 - 0.25X_4X_8 + 0.23X_5X_8 + 0.06X_6X_8 + 0.30X_1X_2X_5 + 0.09X_1X_2X_8$	0.99
Texture	$Y_{26} = 6.61 - 0.07X_1 + 0.08X_2 - 0.13X_3 + 0.07X_4 - 0.10X_5 + 0.001X_6 + 0.03X_7 - 0.23X_8 - 0.16X_1X_2 - 0.07X_1X_4 + 0.14X_1X_5 - 0.16X_1X_8 + 0.07X_2X_5 - 0.12X_2X_8 - 0.10X_3X_5 + 0.07X_3X_7 - 0.2X_3X_8 + 0.12X_5X_6 - 0.14X_5X_7 + 0.15X_7X_8$	0.92
Aroma	$Y_{27} = 5.80 + 0.11X_1 - 0.19X_4 - 0.21X_5 + 0.08X_8 - 0.18X_1X_8 + 0.17X_4X_5$	0.69
General acceptability	$Y_{28} = 6.54 + 0.07X_1 + 0.04X_4 - 0.3X_5 - 0.19X_1X_4$	

APPENDIX 2

ANOVA OF EACH FACTOR AND P-VALUES FOR THE RESPONSES

3.1. ANOVA for Prmax

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	2.119E+06	1	2.119E+06	166.92	< 0.0001
A-PUREE	2.119E+06	1	2.119E+06	166.92	< 0.0001
Residual	63479.67	5	12695.93		
Cor Total	2.183E+06	6			

3.2. ANOVA for Water absorption

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	50.50	1	50.50	102.11	< 0.0001
A-PUREE	50.50	1	50.50	102.11	< 0.0001
Residual	2.97	6	0.4946		
Cor Total	53.47	7			

3.3. ANOVA for Lightness (L*)

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	839.79	13	64.60	26.49	< 0.0001
A-SUGAR	0.6888	1	0.6888	0.2825	0.6016
B-SALT	4.64	1	4.64	1.90	0.1847
E-PUREE	469.44	1	469.44	192.50	< 0.0001
F-ASCORBIC ACID	4.97	1	4.97	2.04	0.1707
G-VARIETY	27.17	1	27.17	11.14	0.0037
H-TREATMENTS	170.22	1	170.22	69.80	< 0.0001
AB	0.3994	1	0.3994	0.1638	0.6905
AH	21.21	1	21.21	8.70	0.0086
BE	16.45	1	16.45	6.75	0.0182
BH	0.3170	1	0.3170	0.1300	0.7226
EH	50.51	1	50.51	20.71	0.0002
FH	41.05	1	41.05	16.83	0.0007
ABH	32.71	1	32.71	13.41	0.0018
Residual	43.90	18	2.44		
Cor Total	883.69	31			

3.4. ANOVA for Redness (a*)

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	160.79	11	14.62	87.15	< 0.0001
A-SUGAR	0.0118	1	0.0118	0.0705	0.7934
B-SALT	0.6801	1	0.6801	4.05	0.0577
E-PUREE	149.93	1	149.93	893.86	< 0.0001
F-ASCORBIC ACID	0.0262	1	0.0262	0.1560	0.6971
G-VARIETY	2.41	1	2.41	14.38	0.0011
H-TREATMENTS	0.5658	1	0.5658	3.37	0.0812
AF	1.30	1	1.30	7.74	0.0115
BH	1.76	1	1.76	10.47	0.0041
EF	1.23	1	1.23	7.34	0.0135
EH	1.11	1	1.11	6.61	0.0183
FH	1.78	1	1.78	10.61	0.0039
Residual	3.35	20	0.1677		
Cor Total	164.15	31			

3.5. ANOVA for Yellowness (b*)

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	800.47	4	200.12	37.01	< 0.0001
C-FAT	4.55	1	4.55	0.8412	0.3672
D-YEAST	0.6541	1	0.6541	0.1210	0.7307
E-PUREE	768.66	1	768.66	142.15	< 0.0001
CD	26.60	1	26.60	4.92	0.0352
Residual	146.00	27	5.41		
Cor Total	946.47	31			

3.6. ANOVA for Weight

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	47227.93	1	47227.93	383.65	< 0.0001
E-PUREE	47227.93	1	47227.93	383.65	< 0.0001
Residual	3446.80	28	123.10		
Cor Total	50674.73	29			

3.7. ANOVA for Volume

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	7.891E+05	12	65759.15	7.62	0.0002
A-SUGAR	67618.28	1	67618.28	7.84	0.0128
C-FAT	687.83	1	687.83	0.0797	0.7813
D-YEAST	3.994E+05	1	3.994E+05	46.30	< 0.0001
E-PUREE	1.559E+05	1	1.559E+05	18.07	0.0006
F-ASCORBIC ACID	134.72	1	134.72	0.0156	0.9021
G-VARIETY	6998.95	1	6998.95	0.8113	0.3811
H-TREATMENTS	86729.11	1	86729.11	10.05	0.0059
AC	25101.04	1	25101.04	2.91	0.1074
AF	49416.94	1	49416.94	5.73	0.0293

AH	70405.99	1	70405.99	8.16	0.0114
CH	18022.72	1	18022.72	2.09	0.1676
EG	26422.72	1	26422.72	3.06	0.0992
Residual	1.380E+05	16	8626.33		
Cor Total	9.271E+05	28			

3.8. ANOVA for Specific volume

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	7.04	1	7.04	16.65	0.0003
E-PUREE	7.04	1	7.04	16.65	0.0003
Residual	12.68	30	0.4228		
Cor Total	19.72	31			

3.9. ANOVA for Baking loss

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	67.72	10	6.77	5.36	0.0007
A-SUGAR	0.0002	1	0.0002	0.0002	0.9898
B-SALT	11.97	1	11.97	9.47	0.0059
D-YEAST	23.51	1	23.51	18.62	0.0003
E-PUREE	8.59	1	8.59	6.80	0.0168
G-VARIETY	7.08	1	7.08	5.60	0.0281
H-TREATMENTS	0.9258	1	0.9258	0.7330	0.4020
AB	6.06	1	6.06	4.80	0.0405
AH	3.78	1	3.78	2.99	0.0992
BH	0.0269	1	0.0269	0.0213	0.8854
ABH	9.41	1	9.41	7.45	0.0129
Residual	25.26	20	1.26		
Cor Total	92.98	30			

3.10. ANOVA for Staling rate

Sources	Sum of Squares	df	Mean Square	F-value	p-value
Model	2.61	12	0.2175	9.20	< 0.0001
A-SUGAR	0.4748	1.0	0.4748	20.08	0.0003
B-SALT	0.0021	1.0	0.0021	0.0878	0.7702
C-FAT	0.0026	1.0	0.0026	0.1097	0.7441
D-YEAST	0.6402	1.0	0.6402	27.07	< 0.0001
E-PUREE	0.1798	1.0	0.1798	7.60	0.0125
G-VARIETY	0.0000	1.0	0.0000	0.0009	0.9769
H-TREATMENTS	0.1415	1.0	0.1415	5.99	0.0243
AB	0.4707	1.0	0.4707	19.91	0.0003
AD	0.1633	1.0	0.1633	6.91	0.0166
CE	0.1650	1.0	0.1650	6.98	0.0161
DH	0.2447	1.0	0.2447	10.35	0.0045
EG	0.1253	1.0	0.1253	5.30	0.0328
Residual	0.4493	19	0.0236		
Cor Total	3.06	31			

3.11. ANOVA for Firmness

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	59.03	6	9.84	27.75	< 0.0001
A-SUGAR	0.6177	1	0.6177	1.74	0.1998
D-YEAST	17.35	1	17.35	48.94	< 0.0001
E-PUREE	12.54	1	12.54	35.38	< 0.0001
H-TREATMENTS	9.71	1	9.71	27.40	< 0.0001
AD	7.73	1	7.73	21.79	0.0001
AH	12.54	1	12.54	35.37	< 0.0001
Residual	8.15	23	0.3545		
Cor Total	67.18	29			

3.12. ANOVA for Springiness

Sources	Sum of Square	df	Mean Square	F-value	p-value
Model	0.0466	17	0.0027	11.40	< 0.0001
A-SUGAR	9.550E-06	1	9.550E-06	0.0397	0.8451
B-SALT	0.0002	1	0.0002	0.6866	0.4223
C-FAT	0.0005	1	0.0005	2.22	0.1602
E-PUREE	0.0270	1	0.0270	112.22	< 0.0001
F-ASCORBIC ACID	0.0023	1	0.0023	9.64	0.0084
G-VARIETY	0.0009	1	0.0009	3.72	0.0757
H-TREATMENTS	0.0003	1	0.0003	1.33	0.2694
AB	0.0003	1	0.0003	1.26	0.2820
AC	0.0014	1	0.0014	5.62	0.0339
AG	0.0018	1	0.0018	7.67	0.0159
AH	0.0001	1	0.0001	0.3208	0.5808
BH	0.0021	1	0.0021	8.75	0.0111
CE	0.0020	1	0.0020	8.32	0.0128
CG	0.0008	1	0.0008	3.45	0.0862
CH	0.0014	1	0.0014	5.97	0.0296
EG	0.0077	1	0.0077	32.20	< 0.0001
ABH	0.0054	1	0.0054	22.28	0.0004
Residual	0.0031	13	0.0002		
Cor Total	0.0497	30			

3.13. ANOVA for Cohesiveness

Sources	Sum of Square	df	Mean Square	F-value	p-value
Model	0.0252	18	0.0014	9.53	0.0004
A-SUGAR	0.0000	1	0.0000	0.0838	0.7781
B-SALT	0.0002	1	0.0002	1.33	0.2754
C-FAT	0.0065	1	0.0065	44.23	< 0.0001
D-YEAST	0.0007	1	0.0007	4.86	0.0521
E-PUREE	0.0010	1	0.0010	6.49	0.0290
F-ASCORBIC ACID	0.0030	1	0.0030	20.66	0.0011
G-VARIETY	0.0003	1	0.0003	1.86	0.2023
H-TREATMENTS	0.0010	1	0.0010	7.12	0.0235

AD	0.0024	1	0.0024	16.49	0.0023
AE	0.0009	1	0.0009	6.16	0.0325
AG	0.0009	1	0.0009	6.05	0.0337
AH	0.0012	1	0.0012	8.31	0.0163
CD	0.0006	1	0.0006	3.80	0.0798
CE	0.0015	1	0.0015	10.34	0.0092
CH	0.0004	1	0.0004	2.54	0.1423
DE	0.0027	1	0.0027	18.40	0.0016
EH	0.0012	1	0.0012	8.31	0.0163
FH	0.0019	1	0.0019	12.69	0.0052
Residual	0.0015	10	0.0001		
Cor Total	0.0267	28			

3.14. ANOVA for Chewiness

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	59.82	13	4.60	16.99	< 0.0001
A-SUGAR	1.01	1	1.01	3.73	0.0702
B-SALT	0.0001	1	0.0001	0.0004	0.9850
C-FAT	0.1421	1	0.1421	0.5249	0.4786
D-YEAST	14.55	1	14.55	53.73	< 0.0001
E-PUREE	14.47	1	14.47	53.42	< 0.0001
G-VARIETY	0.0388	1	0.0388	0.1432	0.7098
H-TREATMENTS	7.44	1	7.44	27.48	< 0.0001
AC	1.35	1	1.35	4.98	0.0394
AD	5.63	1	5.63	20.79	0.0003
AH	9.80	1	9.80	36.19	< 0.0001
BH	1.58	1	1.58	5.84	0.0272
CE	1.67	1	1.67	6.18	0.0236
GH	1.38	1	1.38	5.10	0.0373
Residual	4.60	17	0.2708		
Cor Total	64.42	30			

3.15. ANOVA for Starch content

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	20.83	14	1.49	80.10	< 0.0001
A-SUGAR	0.0132	1	0.0132	0.7112	0.4108
B-SALT	0.0068	1	0.0068	0.3687	0.5517
C-FAT	0.1570	1	0.1570	8.45	0.0098
D-YEAST	0.1671	1	0.1671	9.00	0.0081
E-PUREE	17.80	1	17.80	958.57	< 0.0001
F-ASCORBIC ACID	0.0056	1	0.0056	0.2994	0.5914
G-VARIETY	0.3548	1	0.3548	19.10	0.0004
H-TREATMENTS	1.45	1	1.45	78.14	< 0.0001
AB	0.0480	1	0.0480	2.58	0.1264
AH	0.0758	1	0.0758	4.08	0.0594
BH	0.0291	1	0.0291	1.57	0.2276
EH	0.3711	1	0.3711	19.98	0.0003

FH	0.1732	1	0.1732	9.32	0.0072
ABH	0.1704	1	0.1704	9.17	0.0076
Residual	0.3158	17	0.0186		
Cor Total	21.14	31			

3.16. ANOVA for TCC

Sources	Sum of Square	df	Mean Squares	F-values	p-values
Model	6.18	14	0.4412	69.66	< 0.0001
A-SUGAR	0.0017	1	0.0017	0.2650	0.6133
B-SALT	0.0055	1	0.0055	0.8612	0.3664
C-FAT	0.0603	1	0.0603	9.52	0.0067
D-YEAST	0.0683	1	0.0683	10.78	0.0044
E-PUREE	5.16	1	5.16	814.10	< 0.0001
F-ASCORBIC ACID	0.0009	1	0.0009	0.1415	0.7114
G-VARIETY	0.1201	1	0.1201	18.96	0.0004
H-TREATMENTS	0.4811	1	0.4811	75.95	< 0.0001
AB	0.0124	1	0.0124	1.96	0.1792
AH	0.0251	1	0.0251	3.97	0.0627
BH	0.0119	1	0.0119	1.88	0.1883
EH	0.0945	1	0.0945	14.92	0.0012
FH	0.0782	1	0.0782	12.35	0.0027
ABH	0.0603	1	0.0603	9.52	0.0067
Residual	0.1077	17	0.0063		
Cor Total	6.28	31			

3.17. ANOVA for β-Carotene

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	163.22	14	11.66	64.14	< 0.0001
A-SUGAR	0.0048	1	0.0048	0.0265	0.8727
B-SALT	0.2297	1	0.2297	1.26	0.2766
C-FAT	1.79	1	1.79	9.85	0.0060
D-YEAST	2.15	1	2.15	11.81	0.0031
E-PUREE	132.63	1	132.63	729.65	< 0.0001
F-ASCORBIC ACID	0.0053	1	0.0053	0.0291	0.8666
G-VARIETY	3.68	1	3.68	20.26	0.0003
H-TREATMENTS	14.20	1	14.20	78.11	< 0.0001
AB	0.3185	1	0.3185	1.75	0.2031
AH	0.7049	1	0.7049	3.88	0.0654
BH	0.3330	1	0.3330	1.83	0.1936
EH	2.57	1	2.57	14.14	0.0016
FH	2.87	1	2.87	15.81	0.0010
ABH	1.73	1	1.73	9.51	0.0067
Residual	3.09	17	0.1818		
Cor Total	166.31	31			

3.18. ANOVA for Vitamin A

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	25.04	13	1.93	24.95	< 0.0001
A-SUGAR	0.1877	1	0.1877	2.43	0.1363
B-SALT	0.1661	1	0.1661	2.15	0.1597
D-YEAST	0.7334	1	0.7334	9.50	0.0064
E-PUREE	14.91	1	14.91	193.22	< 0.0001
F-ASCORBIC ACID	0.0007	1	0.0007	0.0087	0.9269
G-VARIETY	0.6893	1	0.6893	8.93	0.0079
H-TREATMENTS	5.29	1	5.29	68.52	< 0.0001
AB	0.0168	1	0.0168	0.2179	0.6462
AH	0.1506	1	0.1506	1.95	0.1795
BH	0.0304	1	0.0304	0.3933	0.5384
EH	1.08	1	1.08	14.00	0.0015
FH	1.38	1	1.38	17.84	0.0005
ABH	0.3995	1	0.3995	5.18	0.0354
Residual	1.39	18	0.0772		
Cor Total	26.43	31			

3.19. ANOVA for Crude fiber

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	94.45	16	5.90	11.76	< 0.0001
A-SUGAR	1.17	1	1.17	2.33	0.1475
B-SALT	0.2372	1	0.2372	0.4725	0.5023
C-FAT	1.10	1	1.10	2.19	0.1598
E-PUREE	0.0320	1	0.0320	0.0637	0.8042
F-ASCORBIC ACID	5.31	1	5.31	10.58	0.0054
G-VARIETY	25.51	1	25.51	50.82	< 0.0001
H-TREATMENTS	0.6541	1	0.6541	1.30	0.2716
AC	14.16	1	14.16	28.20	< 0.0001
AF	4.17	1	4.17	8.32	0.0114
BE	3.27	1	3.27	6.51	0.0222
BH	4.70	1	4.70	9.36	0.0079
CE	7.72	1	7.72	15.37	0.0014
CG	7.82	1	7.82	15.58	0.0013
CH	5.28	1	5.28	10.51	0.0055
EF	6.54	1	6.54	13.03	0.0026
GH	6.77	1	6.77	13.49	0.0023
Residual	7.53	15	0.5020		
Cor Total	101.98	31			

3.20. ANOVA for Reducing sugar

Sources	Sum of Square	df	Mean Squares	F-values	p-values
Model	184.38	14	13.17	79.94	< 0.0001
A-SUGAR	0.1175	1	0.1175	0.7135	0.4100
B-SALT	0.0610	1	0.0610	0.3704	0.5508

C-FAT	1.40	1	1.40	8.47	0.0097
D-YEAST	1.48	1	1.48	9.00	0.0080
E-PUREE	157.61	1	157.61	956.66	< 0.0001
F-ASCORBIC ACID	0.0493	1	0.0493	0.2993	0.5914
G-VARIETY	3.14	1	3.14	19.05	0.0004
H-TREATMENTS	12.84	1	12.84	77.96	< 0.0001
AB	0.4240	1	0.4240	2.57	0.1271
AH	0.6717	1	0.6717	4.08	0.0595
BH	0.2589	1	0.2589	1.57	0.2270
EH	3.28	1	3.28	19.90	0.0003
FH	1.53	1	1.53	9.31	0.0072
ABH	1.51	1	1.51	9.17	0.0076
Residual	2.80	17	0.1648		
Cor Total	187.18	31			

3.21. ANOVA for Protein

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	134.94	13	10.38	30.22	< 0.0001
A-SUGAR	0.7038	1	0.7038	2.05	0.1695
B-SALT	0.7870	1	0.7870	2.29	0.1475
D-YEAST	3.38	1	3.38	9.84	0.0057
E-PUREE	91.07	1	91.07	265.08	< 0.0001
F-ASCORBIC ACID	0.0112	1	0.0112	0.0326	0.8588
G-VARIETY	3.60	1	3.60	10.49	0.0046
H-TREATMENTS	21.91	1	21.91	63.78	< 0.0001
AB	0.1202	1	0.1202	0.3498	0.5616
AH	0.7689	1	0.7689	2.24	0.1520
BH	0.1320	1	0.1320	0.3844	0.5430
EH	4.11	1	4.11	11.95	0.0028
FH	6.34	1	6.34	18.46	0.0004
ABH	2.01	1	2.01	5.85	0.0264
Residual	6.18	18	0.3435		
Cor Total	141.13	31			

3.22. ANOVA for AML: AMP

Sources	Sum of Square	df	Mean Squares	F-values	p-values
Model	0.2700	13	0.0208	25.76	< 0.0001
A-SUGAR	0.0021	1	0.0021	2.57	0.1265
B-SALT	0.0017	1	0.0017	2.13	0.1613
D-YEAST	0.0076	1	0.0076	9.38	0.0067
E-PUREE	0.1214	1	0.1214	150.52	< 0.0001
F-ASCORBIC ACID	0.0003	1	0.0003	0.3952	0.5375
G-VARIETY	0.0068	1	0.0068	8.44	0.0094
H-TREATMENTS	0.0851	1	0.0851	105.55	< 0.0001
AB	0.0004	1	0.0004	0.4866	0.4944
AH	0.0010	1	0.0010	1.27	0.2745
BH	0.0006	1	0.0006	0.6901	0.4170

EH	0.0238	1	0.0238	29.46	< 0.0001
FH	0.0149	1	0.0149	18.45	0.0004
ABH	0.0044	1	0.0044	5.50	0.0307
Residual	0.0145	18	0.0008		
Cor Total	0.2845	31			

3.23. ANOVA for Moisture Content

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	343.13	9	38.13	8.64	< 0.0001
A-SUGAR	14.89	1	14.89	3.37	0.0798
D-YEAST	0.4346	1	0.4346	0.0985	0.7566
E-PUREE	121.55	1	121.55	27.54	< 0.0001
F-ASCORBIC ACID	14.58	1	14.58	3.30	0.0828
G-VARIETY	7.04	1	7.04	1.60	0.2197
H-TREATMENTS	2.51	1	2.51	0.5677	0.4592
AD	43.29	1	43.29	9.81	0.0049
EG	101.30	1	101.30	22.95	< 0.0001
FH	37.53	1	37.53	8.50	0.0080
Residual	97.11	22	4.41		
Cor Total	440.24	31			

3.24. ANOVA for Appearance

Sources	Sum of Square	df	Mean Squares	F-values	p-values
Model	5.71	6	0.9512	5.44	0.0014
A-SUGAR	0.2156	1	0.2156	1.23	0.2790
C-FAT	0.9543	1	0.9543	5.45	0.0290
E-PUREE	0.3955	1	0.3955	2.26	0.1470
F-ASCORBIC ACID	0.0537	1	0.0537	0.3067	0.5853
AE	1.71	1	1.71	9.80	0.0049
EF	1.89	1	1.89	10.78	0.0034
Residual	3.85	22	0.1750		
Cor Total	9.56	28			

3.25. ANOVA for Crumb colour

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	10.65	14	0.7609	9.60	< 0.0001
A-SUGAR	0.2325	1	0.2325	2.93	0.1060
B-SALT	2.78	1	2.78	35.03	< 0.0001
C-FAT	0.0177	1	0.0177	0.2228	0.6433
E-PUREE	0.1487	1	0.1487	1.88	0.1897
F-ASCORBIC ACID	0.0794	1	0.0794	1.00	0.3316
H-TREATMENTS	0.0612	1	0.0612	0.7725	0.3925
AB	0.3381	1	0.3381	4.27	0.0554
AC	0.8397	1	0.8397	10.60	0.0050
AE	0.0058	1	0.0058	0.0727	0.7908
BE	0.0212	1	0.0212	0.2674	0.6122
CE	2.16	1	2.16	27.21	< 0.0001
CH	3.48	1	3.48	43.96	< 0.0001
EF	1.23	1	1.23	15.48	0.0012
ABE	0.9736	1	0.9736	12.29	0.0029
Residual	1.27	16	0.0792		
Cor Total	11.92	30			

3.26. ANOVA for Crust colour

Sources	Sum of Square	df	Mean Squares	F-values	p-values
Model	11.19	14	0.7992	7.54	0.0001
A-SUGAR	0.0007	1	0.0007	0.0061	0.9385
B-SALT	0.3616	1	0.3616	3.41	0.0833
C-FAT	0.5780	1	0.5780	5.45	0.0329
D-YEAST	1.88	1	1.88	17.71	0.0007
E-PUREE	0.1067	1	0.1067	1.01	0.3306
G-VARIETY	0.0723	1	0.0723	0.6823	0.4210
H-TREATMENTS	0.0325	1	0.0325	0.3067	0.5874
AB	0.5215	1	0.5215	4.92	0.0414
AE	2.59	1	2.59	24.39	0.0001
BE	8.211E-08	1	8.211E-08	7.747E-07	0.9993
CD	1.76	1	1.76	16.60	0.0009
DE	2.13	1	2.13	20.11	0.0004
GH	0.5730	1	0.5730	5.41	0.0335
ABE	0.7365	1	0.7365	6.95	0.0180
Residual	1.70	16	0.1060		
Cor Total	12.88	30			

3.27. ANOVA for Flavor

Sources	Sum of Square	df	Mean Squares	F-values	p-values
Model	13.64	24	0.5684	43.02	< 0.0001
A-SUGAR	0.8646	1	0.8646	65.45	0.0002
B-SALT	0.2613	1	0.2613	19.78	0.0043
C-FAT	0.0006	1	0.0006	0.0425	0.8435

D-YEAST	0.1754	1	0.1754	13.28	0.0108
E-PUREE	5.51	1	5.51	417.02	< 0.0001
F-ASCORBIC ACID	0.0458	1	0.0458	3.47	0.1119
G-VARIETY	1.01	1	1.01	76.20	0.0001
H-TREATMENTS	0.7486	1	0.7486	56.67	0.0003
AB	0.0104	1	0.0104	0.7837	0.4101
AC	0.1745	1	0.1745	13.21	0.0109
AE	0.5426	1	0.5426	41.07	0.0007
AF	0.0531	1	0.0531	4.02	0.0917
AH	0.5847	1	0.5847	44.26	0.0006
BE	0.7882	1	0.7882	59.66	0.0002
BH	0.5908	1	0.5908	44.72	0.0005
CD	0.4983	1	0.4983	37.72	0.0009
CE	0.0050	1	0.0050	0.3766	0.5619
CH	0.4597	1	0.4597	34.80	0.0011
DE	0.1169	1	0.1169	8.85	0.0248
DH	1.63	1	1.63	123.23	< 0.0001
EH	1.38	1	1.38	104.36	< 0.0001
FH	0.1334	1	0.1334	10.10	0.0191
ABE	2.45	1	2.45	185.20	< 0.0001
ABH	0.1898	1	0.1898	14.36	0.0091
Residual	0.0793	6	0.0132		
Cor Total	13.72	30			

3.28. ANOVA for Texture

Sources	Sum of Square	df	Mean Squares	F-values	p-values
Model	9.84	20	0.4920	6.48	0.0014
A-SUGAR	0.1444	1	0.1444	1.90	0.1953
B-SALT	0.2264	1	0.2264	2.98	0.1121
C-FAT	0.5114	1	0.5114	6.74	0.0249
D-YEAST	0.1782	1	0.1782	2.35	0.1538
E-PUREE	0.3319	1	0.3319	4.37	0.0605
F-ASCORBIC ACID	0.0000	1	0.0000	0.0004	0.9854
G-VARIETY	0.0372	1	0.0372	0.4898	0.4985
H-TREATMENTS	1.62	1	1.62	21.35	0.0007
AB	0.8549	1	0.8549	11.26	0.0064
AD	0.1365	1	0.1365	1.80	0.2070
AE	0.6412	1	0.6412	8.44	0.0143
AH	0.7855	1	0.7855	10.35	0.0082
BE	0.1790	1	0.1790	2.36	0.1529
BH	0.4782	1	0.4782	6.30	0.0290
CE	0.3363	1	0.3363	4.43	0.0591
CG	0.1627	1	0.1627	2.14	0.1712
CH	1.31	1	1.31	17.19	0.0016
EF	0.4713	1	0.4713	6.21	0.0300
EG	0.6380	1	0.6380	8.40	0.0145
GH	0.8015	1	0.8015	10.56	0.0077
Residual	0.8352	11	0.0759		

Cor Total	10.68	31			

3.29. ANOVA for Aroma

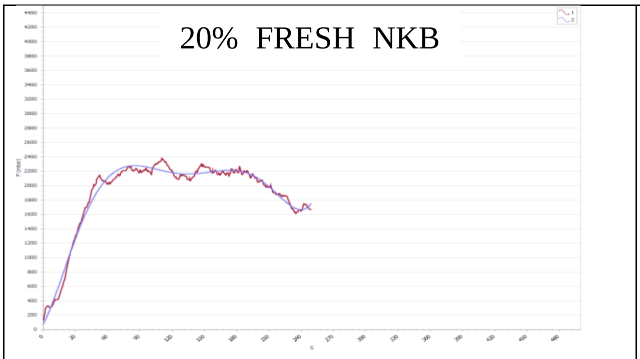
Sources	Sum of Square	df	Mean Squares	F-values	p-values
Model	4.83	6	0.8054	8.54	< 0.0001
A-SUGAR	0.3525	1	0.3525	3.74	0.0656
D-YEAST	1.06	1	1.06	11.25	0.0027
E-PUREE	1.34	1	1.34	14.19	0.0010
H-TREATMENTS	0.1745	1	0.1745	1.85	0.1869
AH	0.9584	1	0.9584	10.17	0.0041
DE	0.8252	1	0.8252	8.75	0.0070
Residual	2.17	23	0.0943		
Cor Total	7.00	29			

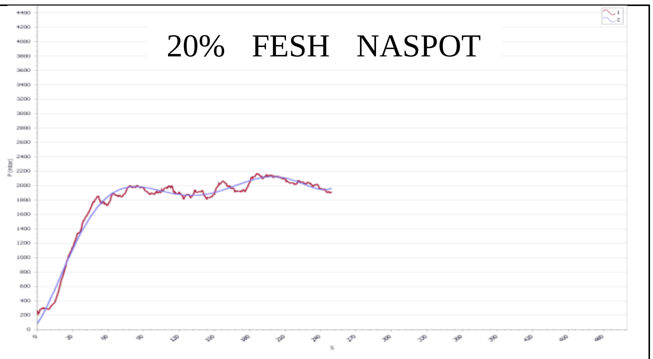
3.30. ANOVA for General acceptability

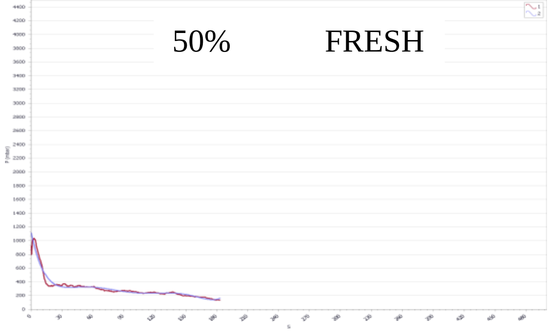
Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	4.19	4	1.05	6.95	0.0006
A-SUGAR	0.1692	1	0.1692	1.12	0.2991
D-YEAST	0.0482	1	0.0482	0.3200	0.5765
E-PUREE	2.80	1	2.80	18.59	0.0002
AD	1.16	1	1.16	7.73	0.0100
Residual	3.92	26	0.1508		
Cor Total	8.11	30			

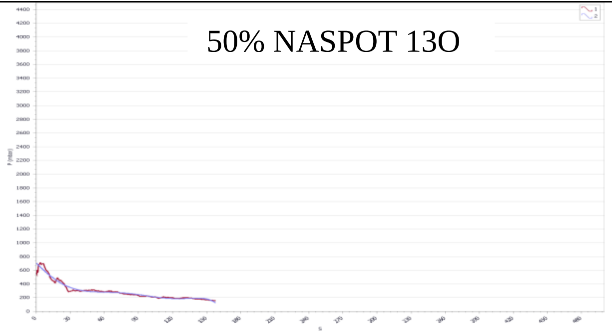
APPENDIX 3

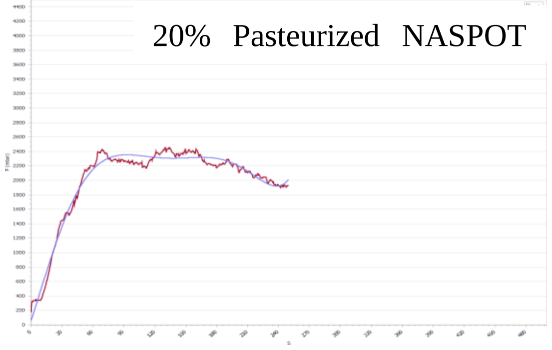
ALVEOCONSTISTOGRAPHIC PROFILE OF WHEAT FLOUR/UNPEELED OFSP PUREE COMPOSITE DOUGH

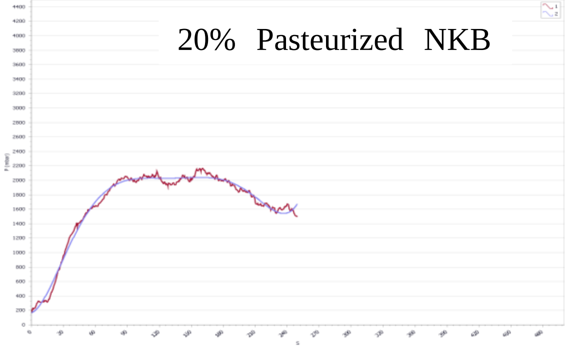

20% FRESH NKB


20% FESH NASPOT


50% FRESH


50% NASPOT 13O


20% Pasteurized NASPOT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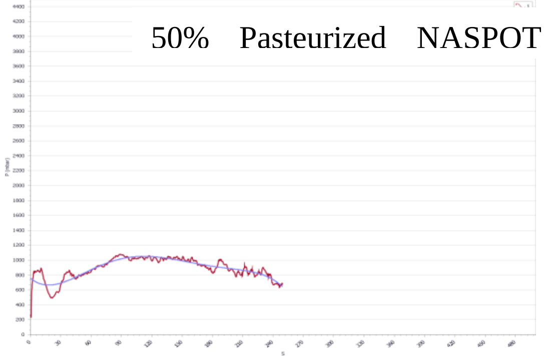
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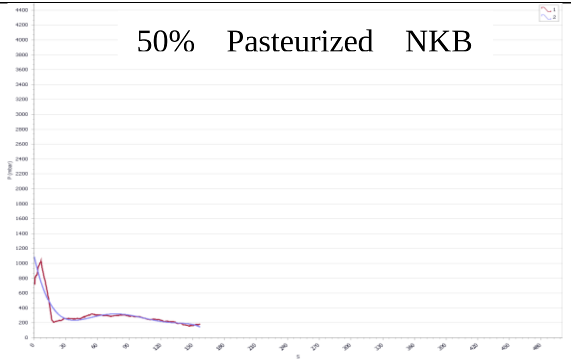
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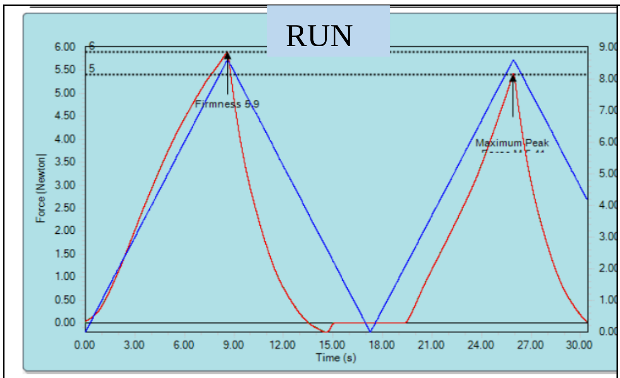
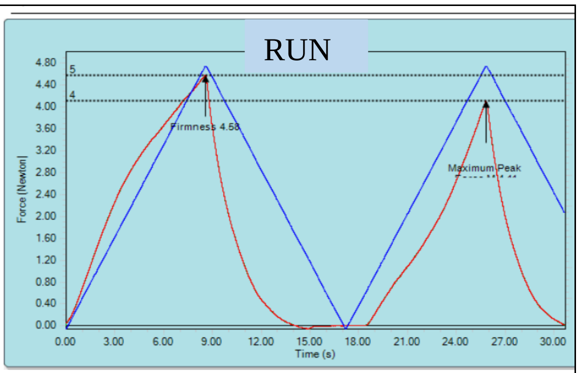
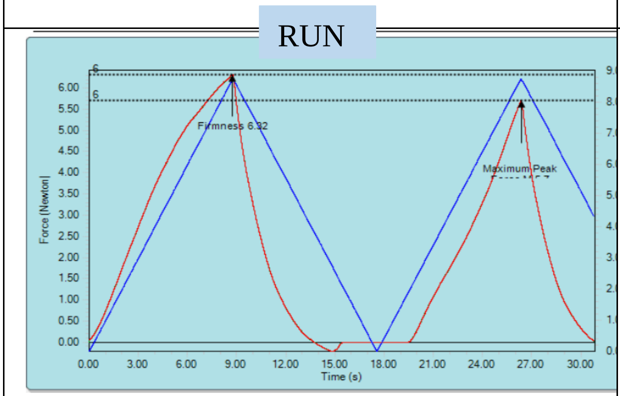
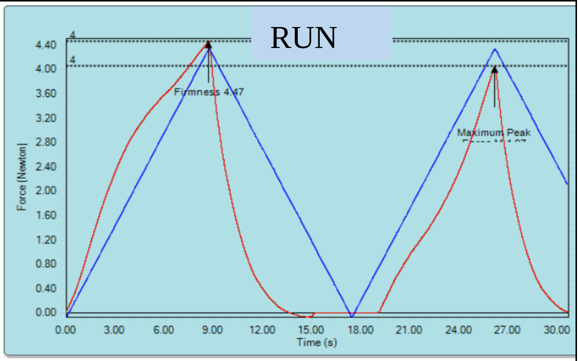
APPENDIX 4

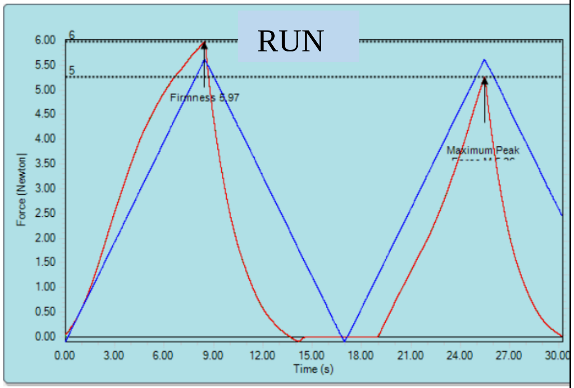
SOME TEXTURE PROFILE ANALYSIS REPORTS

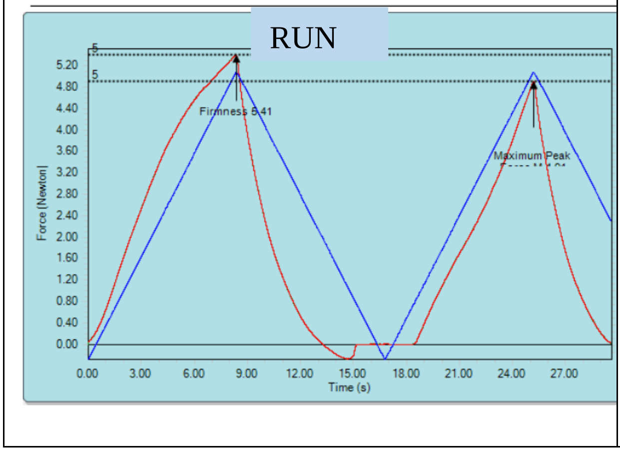


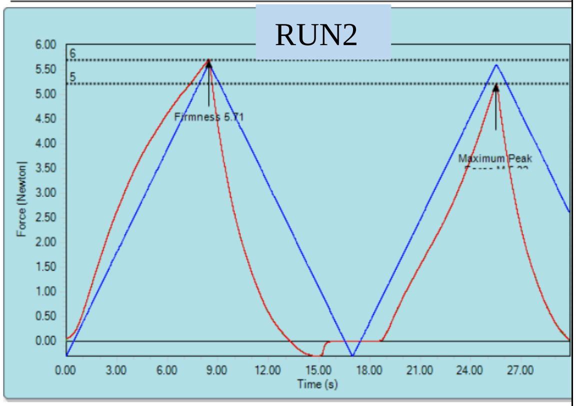












APPENDIX 5

SENSORY EVALUATION OF WHEAT-OFSP BREAD

Panelist number **1** Date……………… time …………
Phone………………….

Instruction

i. You are provided with 5 coded samples of the above-mentioned product.
ii. You are required to evaluate each of them and record your liking of the samples on the scale of 1 to 9 by placing your score in the box next to the sensory parameter under each sample in the table below.
iii. After tasting each sample, rinse your mouth properly with drinking water provided before tasting another sample.
iv. Please judge each sample independently.

Score the products using hedonic scale below	
Like extremely	**9**
Like very much	**8**
Like moderately	**7**
Like slightly	**6**
Neither like nor dislike	**5**
Dislike slightly	**4**
Dislike moderately	**3**
Dislike very much	**2**
Dislike extremely	**1**

Quality attributes	**Sample codes**				
	498	386	569	197	813
Appearance					
Crust colour					
Crumb Colour					
Flavour/Taste					
Texture/Consistency					
Aroma/smell					
General acceptability					

Which sample (only one) would you buy and why? (Clearly write the sample code)

....

General comments:

……………………………………………………………………………………………

Thank you for participating in this exercise

APPENDIX 6

BAKED SAMPLE LOAVES FROM SOME OF THE EXPERIMENTAL RUNS


R1


R8


R15


R29


R7


R23

R26