PRODUCTION AND CHARACTERIZATION OF POTATO FLOUR AND ITS APPLICATION IN NOODLES PROCESSING

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Production and Characterization of Potato Flour and its Application in Noodles Processing

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other university.

Signature………………………………… Date…………………………………

Ariel Kasangi Buzera

This thesis has been submitted for examination with our approval as university supervisors.

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DEDICATION

I dedicate this work to my parents Balzac Buzera and Neema Lubala. To my siblings Arthemie, Arlene, Arlette_Bampa, Ariane_Bienvenu, Armel, Arsène_Ruth. To my charming fiancée, Laureine.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ACRONYMS AND ABBREVIATIONS

AAS	Atomic Absorption Spectrophotometer
ANOVA	Analysis of Variance
AOAC	Association if Official Analytical Chemists
BV	Biological value
CI	Compressibility Index
ESEM	Environment Scanning Electron Microscopy
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture Organization Statistics
GI	Glycemic Index
HTB_OD	High Temperature Blanching_Oven Drying
JKUAT	Jomo Kenyatta University of Agriculture and Technology
LTB_OD	Low Temperature Blanching_Oven Drying
MoA	Ministry of Agriculture
MT	Megatons
NPCK	National Potato Council of Kenya
OEC	Observatory of Economic Complexity
RVA	Rapid Visco Analyzer
SEM	Scanning Electron Microscopy
SPSS	Statistical Package of the Social Sciences
TPA	Texture Profile Analysis
UEA	Université Evangelique en Afrique
UFLC	Ulta Fast Liquid Chromatograph
WHO	World Health Organization

DEFINITION OF OPERATIONAL TERMS

Food	Any substance consumed by the organism for nutritional support
Functional food	Food that contain, in addition to nutrients, other components that may be beneficial to health.
Functionality	The quality or state of being functional
Food Processing	Food processing refers to the set of methods and techniques used to transform raw ingredients into consumable food products.
Food pre-treatment	Food pretreatments refer to the preliminary steps or processes applied to raw food materials before the main processing or cooking.
Potato Flour	A type of flour produced form cooked, dried, and ground potatoes. It is used as an ingredient in potato-based recipes to enhance the potato flavor and is often mixed with types of flour baking.
Noodles	A type of food made from unleavened dough which is either rolled flat and cut, stretched, or extruded, into long strips or strings.

ABSTRACT

Potato (*Solanum tuberosum* L.) is an excellent source of carbohydrates and dietary fibre whose nutritional characteristics are essential in human consumption. However, freshly harvested potatoes are perishable and undergo postharvest loss partly due to limited availability of cold storage facilities. Drying is a common practice for preserving perishable food crops. Potato tubers can be dried and processed into flour using conventional or innovative drying technologies. The flour has a long shelf-life stability due to its low moisture content, and it maintains the nutritional and flavor quality of fresh potatoes. This study aimed to demonstrate the potential use of potato flour produced using different processing in noodle processing, while highlighting its unique nutritional and functional properties. The first part of this study investigated the effects of pre-treatments: low-temperature blanching (LTB) at 60°C for 30 minutes, high-temperature blanching, (HTB) at 95°C for 1 minute, boiling, and drying methods: oven drying (OD) at 50°C for 48 hours and freeze-drying (FD) on the physicochemical, functional, rheological, and morphological properties of potato flour. The flour was derived from three potato varieties namely, Shangi, Unica, and Dutch Robjin obtained from a farmer in Nyandarua county. The percentage flour yield, physical properties, microstructural characteristics, nutritional quality and functional (swelling power, solubility index and pasting) properties were determined. Potato flours that demonstrated good pasting properties were used to substitute wheat flour at 10%, 30% and 50% levels to make composite flours for instant noodles production. Particle size and pasting properties of composite flour, dough mixing behaviour and microstructure of the dough were also investigated. The substitution effects on colour, cooking, textural, and sensory properties noodles were evaluated. The results showed that Unica recorded the least peeling loss (8%), while the Dutch Robjin variety had the highest (25%). The pre-treatments and drying methods significantly affected colour parameters ($p < 0.05$). Freeze drying produced lighter potato flour ($L^* = 92.86$) compared to the other methods. Boiling_OD and HTB_OD recorded a low angle of repose and compressibility index, indicating better flow characteristics. The smallest particle size (56.5 µm) was recorded for the freeze-drying treatment, while Boiling_OD had the largest particle size (307.5 µm). Microstructural results indicate that Boiling_OD and HTB_OD, resulted in damaged starch granules, while freeze-drying and LTB_OD maintained the native starch granule. The results indicated that freeze-dried flour exhibited higher protein content, sucrose, and magnesium content in all different varieties. In comparison, Boiling_OD flour showed the lowest protein, sucrose, and magnesium content in different varieties. The swelling power and solubility index significantly increased as the temperature increased from 50 to 90°C. Particle size and the solubility index of potato flour showed a strong positive correlation. All the potato flour types demonstrated a decrease in apparent viscosity with increasing shear rate, with freeze-dried flour having the highest apparent viscosity. Freeze-dried flour showed the highest peak viscosity (7098.33 cP) and breakdown viscosity (2672.00 cP). The highest final viscosity (7989.00 cP) was recorded in HTB_OD potato flour. Substituting wheat flour with freeze-dried flour significantly decreased the mean particle size of the blended flour, while LTB_OD flour increased the mean particle size. Adding potato flour significantly increased the pasting properties of wheat flour, with freeze-dried flour blends having the highest pasting properties compared to LTB_OD flour blends. Substitution of wheat flour with potato flour caused increases in water absorption as well as dough development time. The highest dough development time was attained when LTB_OD potato flour was substituted up to 50 %. The microstructure images showed that the control sample (wheat dough 100%) was characterized by small and large starch granules. The brightness (L^*) of noodles decreased while the redness (a^*) and yellowness (b^*) increased when potato flour was added. Cooking loss significantly ($p \leq 0.05$) increased, with noodles made from LTB_OD flour blends having the highest loss. When the ratio of potato flour reached 30%, the noodle textural properties, including hardness, cohesiveness, gumminess, and chewiness, decreased significantly ($p \leq 0.05$). Substitution of up to 30 % with freeze-dried flour resulted in noodles with the highest overall liking scores. In conclusion, pre-treatments and drying methods affected potato flour's physicochemical parameters differently, resulting in changes in its functionality. Partial replacement of wheat flour with up to 30% freeze-dried potato flour and 10% LTB_OD potato flour produced noodles with acceptable texture and sensory properties. This demonstrates the potential application of potato flour in noodle processing.

CHAPTER ONE

INTRODUCTION

1.1 Background information

Potato (*Solanum tuberosum* L.), known as the Irish potato, is a tuberous plant cultivated worldwide (Food and Agriculture Organization, 2012). It is considered an important source of carbohydrates that is consumed worldwide behind rice, wheat, and maize (Miranda & Aguilera, 2006; Schwartzmann, 2010; Tian et al., 2016). Besides being a valuable source of carbohydrates and dietary fibre, whose nutritional characteristics are important in human consumption (Camire et al., 2009b), potatoes also contain other nutrients that are essential such as vitamins, minerals, and antioxidants (Arun et al., 2015; Burlingame et al., 2009). Potatoes are known to be low-fat food, and their protein, which is approximately 10%, is similar to the protein content of wheat flour and slightly higher than rice and corn (Bártová et al., 2015a). It is considered the fourth staple food after rice, wheat, and maize in most developing countries (Miranda & Aguilera, 2006; Schwartzmann, 2010). In Kenya, potato is the second most important food crop after maize (Janssens et al., 2013a). Besides being a staple food, it generates cash for many Kenyan families (Ministry of Agriculture, 2007). The average production in Kenya is estimated at 8 to 10 tonnes per hectare (Mumia et al., 2018; National Potato Council of Kenya, 2022) compared to a global average yield of 17 tons per hectare (Food and Agriculture Organization Statistics, 2011). Per capita consumption in Kenya is estimated at 29.9 kg/person (FAOSTAT, 2018).

Once harvested, potatoes are used for a variety of purposes. Less than 50 per cent of potatoes harvested are consumed fresh (FAO, 2008). The rest are processed into food products and food ingredients, fed to cattle, and processed into starch for industry applications (FAO, 2008). Fresh potatoes are baked, boiled, or fried and used in various recipes: mashed potatoes, potato soup, and potato salad (FAO, 2008). During processing, potatoes are converted into products that are less bulky, less perishable, and less expensive to store and transport (Javaid et al., 2018a). Many products such as snacks (cookies) (Raigond et al., 2015), instant dried noodles (Javaid et al., 2018b), potato chips (Mariotti et al., 2015), and French fries (Yang et al., 2016) have been processed from potatoes. In Kenya, fried potato products such as French fries and crisps are the most important potato products widely consumed and commercialized (Walingo et al., 2004; Abong et al., 2010).

Potato consumption as food is shifting from fresh potatoes to added-value processed food products (FAO, 2008c; Hong et al., 2017). New potato-based foods such as bread and pasta are being developed considering the dietary habits of consumers (Rupa et al., 2013). This increases the proportion of potatoes in the daily food intake of people. Processing potatoes into flour is possibly the most common method of creating a product that is functionally adequate and remains for an extended period without spoilage (Yang, 2020). Potato flour is made by drying the potato tubers using traditional or conventional methods (Kulkarni et al., 1996; Li et al., 2018b; Falade, 2016; Desale & Sasanatayart, 2017). Drying is a common practice for preserving perishable food crops. It reduces the moisture content of the food and, consequently, the water activity, inhibiting enzymatic degradation of the food and limiting microbial growth (Ratti, 2001). Most local farmers employ the sun or open-air and solar drying methods because of the low operation cost (Udomkun et al., 2020). However, the increased risk of contamination and several uncontrollable factors associated with open-air and solar drying methods calls for safer, more controllable methods for drying agricultural produce (Ratti, 2001). Oven and freeze-drying are employed in industrial food processes (Fombong et al., 2017). The quality and market value of the dehydrated product by oven and freeze drying, which is not altered by changing weather conditions, is higher than in sun or solar drying. Oven or freeze-drying conditions can be controlled to give the dehydrated product the most desired quality characteristics (Fombong et al., 2017; Zhu et al., 2019).

Potato flour has a more comprehensive nutritional profile such as carbohydrates, protein (Elżbieta, 2012). The lysine content of potatoes is close to that of animal protein, and potato flour can be used to overcome protein and calorie deficiencies (Anjum M et al., 2008). Gong (2010) has reported that potato protein recognized as a nutraceutical component. The antioxidant activities of potato protein hydrolysates were also reported on by Kudo et al (2009) who reported that they were able to protect the gastric mucosal layer against oxidative damage in rats. Besides the important nutrition aspects, potato flour also has important functional properties that determine its potential use in product development (Babić et al., 2006; Song et al., 2017; Ríos-Ríos et al., 2016; Duan et al., 2017; Yadav et al., 2006). The low moisture content, long shelf life, easy storage, and transportation make potato flour easy to use in a range of situations (Lingling et al., 2019; Zhang et al., 2002). Due to its compositional and gluten-free characteristics, potato flour can be a good substitute for cereal crops (Nawaz et al., 2019a). Studies have shown that adding potato flour significantly contributes to maintaining the quality characteristics of products due to its starch content, structural protein differences, and type of protein (Bártová et al., 2015b). Potato flour protein is characterized by a balanced amino acid composition which improves the deficiency of cereal protein and dietary fibre (Bártová et al., 2015b).

The baking industry uses potato flour, which is incorporated into baking bread to retain its freshness (Ezekiel & Singh, 2011). It also imparts a distinctive, pleasing flavour and improves toasting qualities (Avula, 2005; Seelam, 2017; Li et al., 2018a; Liu et al., 2016). Nawaz et al. (2019a) reported the feasibility of adding 40% potato flour to noodles for acceptable physicochemical and functional properties. Bao et al. (2021) reported 40% of potato flour as the maximum amount in fresh noodles. Olivera-Montenegro et al. (2022), found 20% of potato flour was the best treatment to produce dry noodles. Abdul Momin Sheikh et al. (2022) reported that noodles containing 30% potato flour were most preferred in terms of color. Another study reported that adding potato flour enhanced pasta's textural properties (Pu et al., 2017a). Adding some potato flour to making bread could improve the nutritional value and reduce the deterioration rate of bread, and the storage time would be prolonged (Lingling et al., 2019a). Blending wheat flour with potato flour affects the starch–protein matrix, textural characteristics, cooking qualities, starch, and protein quality (Nawaz et al., 2019a). Studies on potato flour in Kenya are still limited. Kabira & Imungi (1991) reported that potato flour could be incorporated to replace up to 40 % of the maize meal in Ugali and Uji without undesirable alteration in their physicochemical and sensory characteristics. Therefore, the current study aims to investigate the potential application of potato flour for food products development in Kenya, specifically in noodles.

1.2 Problem statement

In Kenya, Potato (*Solanum tuberosum* L.), a good source of carbohydrates, is available locally and is cheap compared to staple cereals (Ek et al., 2012). However, the post-harvest quantitative and qualitative changes in the potatoes contribute to the sizeable loss of the crop during subsequent storage, leading to reduced supplies to consumers and inflation of the prices (Lingling et al., 2019). The most frequently stated cause of losses at the farm level in Kenya is disease. This cause was reported by 80% of farmers who experienced a loss in quantity during harvest, and 78% who experienced storage losses (IFPRI, 2020). Kaguongo et al. (2014), reported that 83.9% of farmers experiencing loss during storage, mainly caused by rotten potatoes (82.5%). Each season, 2,760 kg, equivalent to 19.4% of production per hectare, is lost or damaged, leading to a value loss of KES 42,824 (EUR 363) per hectare (Sigrid et al. 2014). The most common potato variety in Kenya, Shangi, has been reported to have the poorest storability having exhibited the highest weight loss (35.13%), sprouting (31 days) and rooting incidence (13.79%), compared to Unica and Dutch Robjin (Gikundi et al. 2022). Beside the utilization of potato for fresh consumption (boiled, fried, used in stew, mashed), for livestock feed and as seed potatoes, the value-added products from potatoes are still limited in Kenya. The exploitation of potatoes in food applications has not been optimally utilized due to a lack of knowledge on proper processing techniques and their impact on the functional and nutritional properties. Limited studies have been reported to investigate the potential of incorporating potato flour into food products such as noodles. Furthermore, the physico-chemical, microstructural, and functional properties of potato flour and how they affect product development have not been investigated in Kenya.

1.3 Justification

Considering Kenya's growing population, changes in health, quality of life, industrial applications, and the rising cost of cereals, it's therefore crucial to identify alternative sources of food and to maximize the utilization of the available food. Potato (*Solanum tuberosum* L.) is locally available and goes for a much cheaper price than most cereals (Ek et al., 2012). Wang’ombe and van Dijk, (2015) stated that potato offers a good alternative for diversification from Maize, the staple food in Kenya. Potato is Kenya’s second most important staple crop after maize, grown by more than 800,000 farm households, thus providing food for nearly 4 million household members, and supporting an additional 2 million active in the value chain (Janssens et al., 2013a). The crop has many advantages concerning production and nutrition that make it an ideal complement to maize. Farmers can plant and harvest potatoes thrice per year compared to maize, facilitating a steadier food supply and income (Muthoni & Nyamongo, 2009b). Additionally, due to the rapid shrinkage of arable land on account of population growth and urbanization, there is a high demand for crops that can produce more food, nutrients, and cash per unit of area and time (Food and Agriculture Organization, 2013). Potatoes fit these criteria as they supply more food more quickly and, on less land, than any other major food crop (Gibson & Kurilich, 2013). Several potato cultivars have been developed with aim of improving its production, drought tolerant and disease, but quite old varieties are still gown (Michiel et al. 2016). Some of these varieties are Kenya Mpya, Kenya Karibu, Sherekea, Shangi, Unica, Dutch robjin among others (NPCK, 2017). In addition, newer potato varieties and clones are being developed by the National Potato Research Center (KARI-Tigoni) presumed to be superior to the existing ones in terms of disease tolerance.

Potatoes in Kenya can be used in various industrial processes, such as the production of starch, flour, alcohol for industrial purposes. This diversification of potato utilization would result in numerous benefits to society and the country. Processing the potato tubers into various processed products such as flour is an option that can help extend the shelf-life, solve the storage issues, and increase the supply in off-seasons, thus maximizing potato utilization (Avula, 2005). Due to its nutritional composition characteristics, high functional properties, and gluten-free characteristics, potato flour can be a good substitute for cereal crops such as wheat to make product such as breads, snacks, and noodles (Nawaz et al., 2019a). Noodles, a widely consumed traditional food globally, have emerged as one of the two major flour products worldwide, second only to bread in annual production (Shewry & Hey, 2015). In Kenya, noodles have become a popular food item, especially among urban and younger populations. They are convenient and quick to prepare. Thus, the substitution of wheat flour with potato flour to make noodles can be an effective way of improving the quality of different products and providing health benefits for consumers. This could also create opportunities for the processors, farmers, and traders to make an income which would further assist in reducing poverty as envisioned in sustainable development goal number one and two.

1.4 Objectives

1.4.1 Main objective

To determine the physicochemical properties of potato flour and their impact on functionality targeting noodles production.

1.4.2 Specific objectives

1. To determine the physicochemical characteristics of potato flour from three Kenyan potato varieties prepared under different pre-treatments and drying methods.
2. To determine the functional, and microstructural properties of potato flour as influenced by pre-treatments and drying methods.
3. To evaluate the physical and rheological properties of potato-wheat flour blends to provide a basis for the application in noodles production.
4. To evaluate the effect of potato-wheat flour blends on physical and sensory properties of noodles.

1.5 Null hypothesis

- ✓ There is no significant difference in the physicochemical characteristics of potato flour from the three Kenyan potato varieties when subjected to different pre-treatments and drying methods.
- ✓ There is no significant influence of pre-treatments and drying methods on the functional, and microstructure properties of potato flour.
- ✓ There is no significant difference in the physical and rheological properties between potato-wheat flour blends.
- ✓ There is no significant effect of potato-wheat flour blends on the physical and sensory properties of noodles, and therefore, these blends do not impact the quality of the noodles.

1.6 Outline of this thesis

This thesis is organized into seven well-structured chapters, as illustrated in **Figure 1.1.** The introductory chapter serves as the foundation and comprises of elements such as the research background, problem statement, justification, research objectives, and hypotheses. **Chapter 2** is dedicated to an extensive literature review while **Chapters 3-6** constitute the core of this PhD thesis, each aligning with one of the four specific objectives set forth for this research. Finally, **Chapter 7** serves as the final segment, highlighting the main conclusions and recommendations.

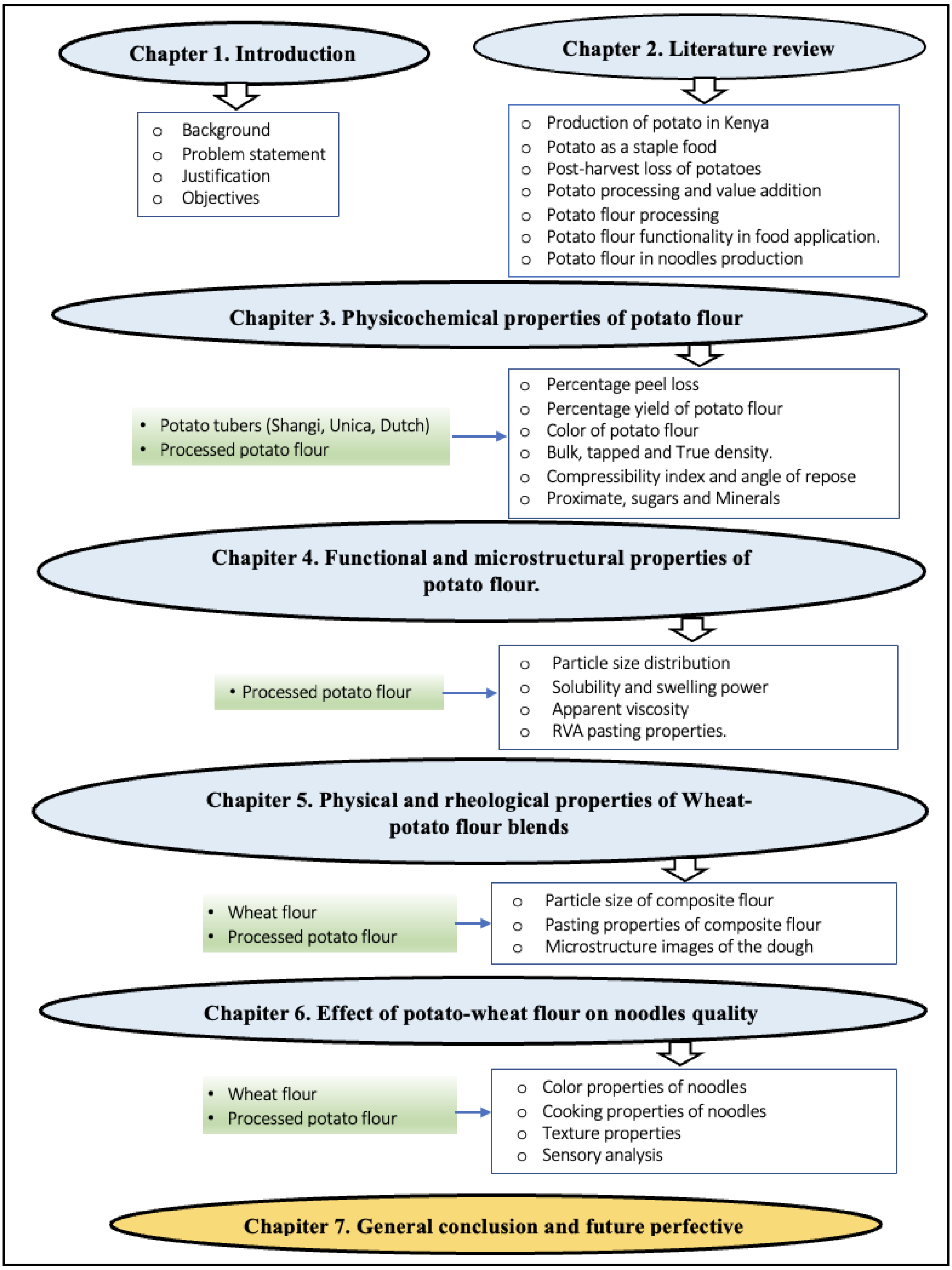


Figure 1.1: Overview of the thesis structure

CHAPTER TWO

LITERATURE REVIEW

2.1 Production of Potato in Kenya

Kenya is the fifth largest producer of potatoes in sub-Saharan Africa, with production and consumption rising faster than any other root crops and cereals (Taiy et al., 2016). Kenya's total area under potato farming is estimated to be 192,341ha, with an average production of 1.5 million metric tons annually (FAOSTAT, 2019a). Potato is an important food and cash crop in Kenya. After maize, it ranks second in production and consumption (Muthoni & Nyamongo, 2009a).

The crop has many advantages concerning production and nutrition that make it an ideal complement to maize, which is Kenya's predominant food security crop. Unlike maize which takes up to 10 months to mature, potatoes have short growing periods of 3-4 months (Muthoni & Nyamongo, 2009b). Farmers can plant and harvest potatoes thrice per year compared to maize, facilitating a steadier food supply and income (Muthoni & Nyamongo, 2009b). Additionally, due to the rapid shrinkage of arable land on account of population growth and urbanization, there is a high demand for crops that can produce more food, nutrients, and cash per unit of area and time (Food and Agriculture Organization, 2013). Potatoes fit these criteria as they supply more food more quickly and, on less land, than any other major food crop (Gibson & Kurilich, 2013). Moreover, the potato has been identified as one of the priority crops in strategies to achieve the food security component of the government’s Big-Four agenda (Mbego, 2019).

Potato production in Kenya is mainly done by small-scale farmers numbering about 800,000, and an estimated of 2.5million people are employed in the potato sub-sector (Lung’aho & Schulte-Geldermann, 2016). It is estimated that 83 % of the land under potato cultivation belongs to smallholders who dedicate 0.2 to 0.6 hectares of their land to potato production. The other 17 % of potato cultivation belongs to medium to large-scale farmers who dedicate 2 to 10 hectares to the crop (Janssens et al., 2013b). Potato, therefore, plays a substantial role as a source of food and nutritional security, and livelihood to many Kenyans. Cultivation of potatoes in Kenya is concentrated in the high-altitude areas (1500-3000 meters above sea level) of Central, Eastern, and Rift Valley regions of Kenya, where other crops such as maize don’t have a comparative advantage (Janssens et al., 2013b). However, some new varieties can also do well in areas with altitudes below 1500 meters above sea level (NPCK, 2017a). Kenya has five major potato-growing zones based on varieties grown, geographic location, and cultivation practices (Kaguongo et al., 2008a). They include Mt. Kenya region (Meru, Nyeri), Aberdares and Eastern Rift Valley region (Nyandarua, Kiambu, Nakuru districts), Mau region comprising Narok and Bomet, Mt. Elgon region (Elgeyo-Marakwet, Uasin-Gishu), and other highlands such as Taita-Taveta in the southern border (Kaguongo et al., 2008b).

Due to the larger average area dedicated to potato production compared to, e.g., Ethiopia and Uganda, Kenyan potato producers can sell a larger proportion of their production after satisfying the needs for home consumption and seed potatoes. In the study by Gildemacher et al. (2009), 87% of the producers sell their potatoes at the farm gate to traders or brokers, 8% sell at village markets, and 5% sell through other channels. Hence, potatoes are often directly sold from the field without being stored by the potato producer. Traders or brokers sell potatoes to wholesalers in urban markets. It is estimated that about 348 tons of potatoes per day are sold at wholesale markets in Nairobi (Ayieko et al., 2006).

2.2 Potential utilization of potatoes as a staple food (Nutritional composition of potato)

Potatoes are an affordable food alternative and are regarded as a carbohydrate-rich food. Carbohydrate content in potatoes constitutes almost 80% of the dry matter (Navarre et al., 2009a). Starch is the main carbohydrate in potatoes (Sawicka & Das Gupta, 2018). Cultivated potatoes have 11.0 – 30.4% starch on a fresh weight basis (mean of 18.8%), while wild species can have up to 39.6% of starch (Jansen et al., 2001). Starch has a semi-crystalline structure composed of amylose and amylopectin on an average ratio of approximately 1:3 (Donnelly & Kubow, 2011). Amylopectin accounts for starch crystallinity and is highly branched, while amylose forms the amorphous and structurally linear component (Ngobese et al., 2017). Amylose is digested slowly compared to amylopectin, resulting in a lower glycemic index (GI). Amylose is less readily digested than amylopectin due to its linear structure and the presence of alpha-1,4-glycosidic bonds. The linear structure of amylose makes it more resistant to enzymatic action, while amylopectin's branched structure allows enzymes to access and break down its glucose units more efficiently during digestion. As a result, the digestion of amylose is a slower process compared to amylopectin (Ngobese et al., 2017). Research has confirmed that amylopectin (AP) is more easily digested than amylose (AM) because AP polymers have more intramolecular hydrogen bonds and less surface area (Yang et al. 2022). Therefore, varieties with a high amylose content are preferred by diet-conscious consumers (Fajardo et al., 2013). Cooked potatoes are an excellent dietary source of carbohydrates, which make up about 75% of the total dry matter of the tuber (Burgos et al., 2020).

Potato protein ranges from 1–1.5% of fresh tuber weight and 8-9 % by dry weight (Ortiz-Medina, 2006). Potato has high-quality protein. Protein quality is often expressed in terms of its “biological value” (BV), which considers the amino acid profile of the protein along with its bioavailability (McGill et al., 2013). Potatoes have a relatively high BV of 90 compared with other key plant protein sources (e.g., soybean with a BV of 84 and beans with a BV of 73). Potatoes contain all nine essential amino acids, and their amino acid profile is comparable to other key vegetable proteins (Woolfe 1987). Gorissen et al. (2018) reported that potato protein was superior to other plant-based and was similar to animal-based proteins in terms of essential amino acid content. Lysine is the most predominant amino acid in the potato, which is deficient in cereals. It is, however, limited in sulphur-containing amino acids, bringing about mutual complementation when incorporated into a cereal diet (Ooko, 2008). Chakraborty et al. (2000) described genetically modified potatoes which were created to contain 35–45% more protein than control, with 2.5 to 4 folds expanded higher lysine, methionine, cysteine, and tyrosine contents.

Lipids are a minor component of potato weight, representing approximately 0.15 g/150 g of raw weight (Haasse & Haverkort, 2006; Camire et al., 2009a). This quantity of fat in potatoes is too low to have a significant nutritional impact. Still, it has been reported to play a substantial role in potato palatability, promoting tuber cellular integrity and resistance to bruising and contributing to reducing enzymatic browning of tuber flesh (Ooko, 2008).

The fiber content in potatoes is relatively low compared to other common vegetables (Leonel et al., 2017a). Dietary fiber is provided by cell walls, particularly the potato peel's thickened cell walls, which comprise 1–2% of the tuber. These non-lignified fibers may have a part to play in decreasing cholesterol levels (Lazarov & Werman, 1996). The fiber content in potatoes helps promote feelings of fullness and satiety, making them an effective food for weight management (Burgos et al., 2020).

Potato also contains considerable amounts of vitamins and minerals. Vitamins C and B complex are the major vitamins contained in potatoes (FAO, 2008a). One medium-sized potato of 150 g provides almost half the daily adult requirement, forming an important dietary source of vitamin C (19.4 mg/100g) (which boosts iron absorption) in many parts of the world (Camire et al., 2009a; FAO, 2008c; Zhang et al., 2017). The vitamin, however, is susceptible to degradation during processing and cooking (Ooko, 2008). Potato also compares well to other vegetables in terms of vitamin B. The B vitamins present in potatoes include folic acid, niacin, pyridoxine, riboflavin, and thiamine (Camire et al., 2009a; Campos & Ortiz, 2020a). Potatoes are particularly considered to be a good source of pyridoxine (vitamin B6), with concentrations ranging between 0.45 to 0.68 mg/100g (fresh weight) (Mooney et al., 2013). This vitamin is also influenced by factors such as light exposure and heat but is relatively stable during storage (Campos & Ortiz, 2020b).

Further, potato is a moderate source of minerals, including iron, potassium, phosphorous, magnesium, zinc, and calcium, which form part of the ash content (Camire et al., 2009a). Ash content in potatoes is approximately 3.5% on a dry weight basis and constitutes minerals essential to various body functions (Abong et al., 2009). Moreover, potato minerals have potentially higher bioavailability than other plant sources (Camire et al., 2009a; Navarre et al., 2009b). This is due to low concentrations of compounds such as phytates and oxalates that would limit mineral absorption (Ekin, 2011). Various studies have observed large variations in the mineral content of raw tubers and their processed forms across varieties. Abong et al. (2009) found significant variations in mineral content among eight cultivars. Iron and zinc contents ranged between 2.65-4.54 mg/100g and 1.77-2.90 mg/100g (Dry basis), respectively. Another study on five Brazilian varieties revealed variations in phosphorous contents, with the lowest-containing variety having 22.77g/100g and the highest one having 30.95mg/100g on a fresh weight basis (Leonel et al., 2017b). Managa (2015) observed that iron and zinc varied significantly among 20 South African cultivars, with the average concentrations ranging between 12.88-66.1 mg/kg for zinc and 34.67-76.67mg/kg for iron. Approximately 63–79% of the potato iron is released from the food matrix after in vitro gastrointestinal digestion, and therefore available for intestinal absorption (Andre et al. 2015). Calcium is present in minor quantities in potato ranging from 2 to 20 mg/100 g FW; contributing no more of 2% of the estimated average requirement of calcium for adults (800–1100 mg per day). One hundred grams of boiled potatoes can contribute up to 16% of the Adequate Intake (AI) of potassium recommended for adults (4700 mg per day) (Burgos et al. 2020).

Despite the potential benefits associated with the consumption of nutrients found in potatoes, there is a current debate concerning epidemiological affiliations regarding using potatoes as a high Glycemic index (GI) food and diabetes risk (Sagili et al., 2022). Halton et al. (2006) observed a positive association between the consumption of potatoes and French fries and an increased occurrence of type 2 diabetes after researching 84,555 women with no history of chronic disease at baseline. Higher consumption of potatoes was significantly associated with a raised risk for type 2 diabetes. More recent studies have shown that total potato consumption is not identified with risk for some chronic diseases but could represent a small increment in risk for type 2 diabetes and hypertension (Schlesinger et al., 2019).

2.3 Post-harvest loss of potatoes in Kenya

Globally, post-harvest losses of potatoes are estimated to be 10-15% annually but can go as high as 30% in developing countries where efficient storage practices have not been fully adopted (Benkeblia et al., 2008). Post-harvest management of potatoes is critical in averting post-harvest losses and preserving their nutritional quality (Musita et al., 2019). Moreover, postharvest management and storage significantly influence the safety of potatoes for consumption. This is due to the formation of glycoalkaloids, a family of steroidal secondary metabolites that are toxic to humans if consumed in large quantities (Musita et al., 2019).

In Kenya, most harvested potatoes are sold locally on the markets as fresh produce to be consumed domestically or processed at the industrial level (Sigrid et al., 2014). Most potato farmers in Kenya sell their produce immediately after harvest or harvest their potatoes upon identifying buyers (FAO, 2013). Potatoes are seldom stored after harvest for future sale, leading to seasonal gluts and shortages (FAO, 2013). This is because smallholder potato farmers lack the knowledge and appropriate systems for potato storage (Nyankanga et al., 2018). Farmers store potatoes in bags in their houses or stores, leading to losses due to decay, sprouting, and greening, among others. In factories, hotels, and restaurants, potatoes are also usually stored for short periods before processing due to their perishable nature (FAO, 2013). According to Kaguongo, Maingi, & Giencke, (2014), 12.8% to 25% of potato losses within in Kenya, are reported at farms, the processing industry, and supermarkets. During each harvest season, approximately 19% of potato per hectare production is lost or damaged, corresponding to a loss of Kenya shillings 42,824 per hectare. When extrapolated to the national production level, these losses translate to approximately 815, 000 tonnes of damaged or lost produce annually, representing a value of about 12 billion Kenya shillings.

Post-harvest losses of potatoes mainly stem from the fact that potatoes are highly perishable due to their high moisture content. Physical and nutritional quality losses occur due to tuber greening, premature and excessive sprouting, rotting, respiration, and transpiration (Nyankanga et al., 2018). Nearly a quarter of the potatoes placed on Kenyan markets are damaged or green in color (Musita et al., 2019). This cause concerns over food losses and the safety of the potatoes to consumers. Sprouting results in weight loss due to water loss from the sprout surfaces and starch remobilization (Alamar et al., 2017). It also leads to diminished nutritional and processing quality of potatoes (Abong et al., 2010).

Minimizing post-harvest losses and extending the shelf life of potatoes is critical, especially given the modern-day food security concerns. Rather than increasing food production, reducing post-harvest losses makes food available to consumers and aids in saving resources and minimizing environmental pollution contributed by intensive farming (Kuyu et al., 2019). Gikundi et al. (2022) explored the effect of different cold storage on the storability of potatoes and found out that some varieties such as Shangi could be stored for over 3 months with minor quality changes. By reducing post-harvest losses of potatoes, more food could be made available faster and without adding pressure to the environment. Even though sprout suppressants could be used to extend the shelf life of potatoes, legislative bodies are limiting their use due to rising environmental and health concerns (Pinhero & Yada, 2016). Due to this, it has prompted alternative non-chemical methods, such as value addition to potatoes, to extend their shelf life.

2.4 Potato processing and value addition in Kenya

Production and value addition of potatoes are important livelihood strategies for many poor smallholder farmers and players in the potato value chain. The processing of potatoes and value addition has gained increasing importance in Kenya to enhance their economic value, reduce post-harvest losses, and provide small-scale farmers with new opportunities. As an alternative to the challenges associated with storing and transporting raw potato tubers, processing them into more stable products such as chips, crisps, starch, or flour is suggested (Abong et al., 2009a). Furthermore, such methods will help extend the supply time of potatoes as a staple and eliminate seasonal limitations (Cui et al., 2018).

In Kenya, urban dwellers represent the country’s main potato consumers and the major contributors to the soaring demand for potatoes and processed potato products such as French fries and crisps. On the other hand, fresh consumption is predominant in rural settings where potatoes are mainly produced (Korir et al., 2020). Generally, Kenya has an expanding food processing industry fueled by the rising preference for fast food by the growing population and the development of towns and cities following the recent devolution (Laititi, 2014).

Potatoes in Kenya lead the pack of fast foods in terms of cost and ease of preparation, among other factors. According to Kaguongo et al. (2014), over 200 potato processing companies are in Kenya, and approximately 9% of Kenyan potato production is processed. French fries account for 5% of the potatoes used in processing, while 3% goes into crisp processing and 1% into producing a variety of snacks (Kaguongo et al., 2014).

The Kenyan market's two main forms of ready-cut chips (fries) are fresh (chilled) and frozen ready cut-fries. The ready-cut fresh chips are chilled to prolong shelf life for up to three weeks, while the frozen fries have a shelf life of up to 10 months. Kaguongo et al. (2014) reported four market segments for ready-cut chips: franchise hotels, home use, and classified and unclassified hotels. Large processors such as the Njoro canning factory process potatoes into French fries and potato cubes, which they supply in frozen form to supermarkets and hotels and restaurants (Taiy et al., 2016). In urban settings, small-scale processors directly produce hawk-cooked French fries for restaurants and hotels. A larger proportion of restaurants and hotels (75%) process their French fries (only about 25% get supplies from processors). In Mombasa and Nairobi, large processors maintain cold stores that demand frozen fries to retail outlets such as supermarkets and hotels (Janssens et al., 2013b).

In Kenya, crisp processing has been conducted for more than four decades. Shangi and Dutch Robjin are the main varieties used for crisp processing in Kenya (Kaguongo et al., 2014). As reported by Kaguongo et al. (2014), approximately 35, 000 tonnes of potatoes are processed into crisps annually in Kenya. The same study showed that there are two crisps processing market segments, namely cottage and large-scale industry. The large-scale industrial processes account for an average of 240 MT of potatoes, while the cottage industry processes an average of 3 MT of potatoes into crisps per month. Half of the crisps produced are retailed in supermarkets by consumers who can afford them, especially residents in large cities such as Nairobi. About 20% is consumed through other distribution channels

(Janssens et al., 2013b). Some crisps are exported to Tanzania, Uganda, and Zimbabwe.

Other popular potato products consumed at the home setting and restaurants include bhajia, baked potatoes, roasted potatoes, mashed potatoes, potato stew, and *mukimo* (a mashed vegetable dish), also known as *kienyeji* (Kaguongo, Maingi, & Giencke, 2014). More potato products, such as starch, potato flour, ethanol, and wine, are not yet commercially processed in Kenya (Janssens et al., 2013b).

Studies on potato flour in Kenya are still limited. Kabira & Imungi (1991) found that potato flour could be incorporated to replace up to 40 % of the maize meal in Ugali and Uji without undesirable alteration in their physicochemical and sensory characteristics.

2.5 Potato flour

Fresh potatoes are prone to perishability and non-storability due to water content and metabolic activity after harvest (Pinhero et al., 2009). Moreover, even under excellent growing conditions, thin and permeable potato skins are most susceptible to excessive weight loss, bud growth, and deterioration (Kaur et al., 2009). The possible method of storing potatoes and preventing further deterioration is by drying treatment of the tubers (Doymaz, 2012). Converting potatoes into potato flour can extend the shelf life of potatoes and reduce storage costs (Bao et al., 2021; Yang, 2020). Potato flour is a product that is not only functionally adequate but can remain for a long period without being spoiled (Avula & Singh, 2009). Due to its versatility in function as a thickener, color enhancer, and flavor enhancer, it is an attractive value-added product (Avula & Singh, 2009).

Potato flour ranks quite high in its supply of principal nutrients like protein, fiber, and carbohydrates. Its protein content is superior to that of cassava and yam flour and similar to that of rice. Potato flour has higher levels of fibre than refined wheat flour, maize meal, and rice. Its carbohydrate and energy contents are comparable to those of similar foods (Kulkarni et al., 1996). The average composition of potato flour is given in **Table 2.1** below:

Table 2.1: Proximate composition of potato flour

Characteristics	g/100g* (Atikur Rahman, 2015)	g/100g* (Avula, 2005)	g/100g* (Higley et al., 2003)
Protein (N × 6.25)	5.3±0.02	9.1±0.1	9.36-10.35
Carbohydrates	81.08±0.01	75.3±1.0	82.52-84.97
Fat	0.95±0.01	0.3±0.02	0.17-0.40
Total dietary Fiber	-	10.6±0.1	-
Ash	3.59	3.0±0.1	4.15-4.55

*Dry weight basis

Potato flour is prepared by cleaning, peeling, and slicing potato tubers, pre-treatments (blanching, boiling, or soaking), drying, grinding, and finally, sieving the end-product (Lingling et al., 2019a). The procedure is standard and differs in the pre-treatments and drying methods (Zhang et al., 2020; Li et al., 2017; Hidayat & Setyadjit, 2019). Drying results in lowering the moisture content of the product, thus leading to reduced chances of microbial growth. Reducing the moisture content of potatoes improves the stability of food since it substantially minimizes degenerative reactions due to physicochemical and microbiological factors (Doymaz, 2012). It also facilitates storage, transportation, and packaging. In addition to extending the shelf life, drying is a classical food preservation method that provides a lighter weight for transportation and minimizes the storage space of potatoes (Doymaz, 2012).

Agricultural products and perishable foodstuffs are commonly subjected to pre-treatments before dehydration, such as speeding up the drying process and preserving the product quality (Sahoo et al., 2015). Among the many pre-treatment technologies for potatoes, the most common ones include blanching and boiling. Pre-treatments and drying have been reported to significantly affect root and tuber flours' functional properties, chemical composition, and sensory characteristics (Haile et al., 2015).

2.6 Pre-treatment methods

2.6.1 Blanching

Blanching entails the process of heating foods rapidly to a pre-set temperature and holding them at that temperature for a certain period, then either cooling the material or taking it immediately to subsequent processing (Kapadiya et al., 2018). Blanching is usually carried out on vegetables and fruits before other forms of processing to inactivate enzymes, texture modification, color preservation, and preservation of nutritional quality (Kapadiya et al., 2018). Additionally, blanching is an important heat treatment to inactivate enzymes such as polyphenol oxidase in potato tubers. Blanching also accelerates the drying rate by changing the physical properties of the samples, such as the permeability of the cell membranes (Deng et al., 2019). Water blanching and steam-blanching remain the most popular commercial pre-treatment methods because they are easy to establish and carry out (Sun et al., 2020). Generally, water blanching results in more uniform treatment and is done in hot water at temperatures ranging between 80–100°C for 20 seconds to 20 minutes (Sun et al., 2020).

Different steam and water blanching systems are designed to increase the drying and dehydration rates by changing physical properties of the products which can improve their quality attributes (Xiao et al. 2017; Kapadiya et al., 2018). Olatunde et al., 2016) reported that the blanching of sweet potatoes led to a substantial reduction in the paste viscosity of the sweet potato flour, irrespective of the drying method. In addition to inactivating spoilage enzymes, blanching of Irish potatoes has been reported to reduce glycoalkaloid content (Rytel et al., 2013). Moreover, blanched potato flour was reported to have a less protein quantity than unblanched flour (do Nascimento & Canteri, 2018a). At the temperatures above 70 °C, the proteases hydrolyze peptide bonds of the proteins, lose their catalytic activity Escaramboni et al. (2013). Thus, the remaining proteolytic enzymes which still active in unblanched potato flour may have caused the reduction of this component. Blanched potato flour (97 °C for 5 minutes) was reported to have higher L* (lightness) values than unblanched flour, which was darker due to the presence of polyphenol oxidase and peroxide enzymes responsible for enzymatic browning reactions (do Nascimento & Canteri, 2018a).

2.6.2 Boiling

Boiling generally refers to the process of heating a liquid substance to its boiling point, at which it undergoes a phase transition from a liquid to a gas (Dincer et al., 2011). The boiling process causes several changes in the physical characteristics and chemical composition of food products (Dincer et al., 2011; Tian et al., 2016; Murayama et al., 2015; Hiroshi & Hiroaki, 2015). In another study, boiling potato tubers before drying resulted in native potato flour with a high L* value which was attributed to the restraining of enzymatic browning effects (Murayama et al., 2015; Zhu et al., 2019). Mujoo & Ali (2000) reported that boiling resulted in low viscosity of potato flour mostly due to their lower carbohydrate content and higher molecular starch degradation. Jayanty et al. (2019) reported that the boiling of peeled potato tuber caused decreased contents of soluble constituents such as carbohydrates and minerals. Murayama et al. (2015) mentioned that boiling increased the particle size by the swelling and adhering of gelatinized starch granules. Wei et al. (2017) in their study on the effect of cooking methods and the sugar composition of sweet potato, reported that boiling decreased starch content, increased sugar content especially reducing sugars, and increased sweetness.

2.7 Drying methods

Potatoes are dried in various ways involving the removal of moisture from the tubers to extend their shelf life and facilitate their storage. Several common drying methods include air drying, drying under the sun, and mechanical drying using specialized equipment such as dehydrators and ovens.

2.7.1 Solar drying

Solar drying is a method of preserving or dehydrating various materials, typically food or agricultural products, using the energy from sunlight. The process involves exposing the material to direct sunlight or using solar devices to harness solar energy, which accelerates the evaporation of moisture, thereby drying the product (Guiné, 2018). Solar drying is being increasingly applied in the drying of agricultural products. Solar drying is recommended as an improvement to open sun drying, which has been reported to be relatively slow. It might result in inadequate drying and contamination with insects and rodents, all of which contribute to poor product quality (Zhang et al., 2020). Solar drying involves a continuous process whereby the product temperature, air, and moisture content change concurrently with the two basic system inputs: solar installation and inlet air at ambient temperature. There are various forms of solar drying, including direct, indirect, hybrid, and forced convection and natural convection solar dryers (Nicanuru, 2016; Sharma & Wadhawan, 2018). Nwofe (2015) reported that processing potatoes by solar drying exhibited a faster drying rate, yielded high-quality products, and was more timesaving than open sun drying. Another important feature of solar drying is that processing usually does not involve adding chemicals such as preservatives, and the product is not exposed to harmful electromagnetic radiation (Dery, 2012).

Furthermore, Nwofe (2015) showed that solar drying of potatoes was an ideal way for farmers to reduce the post-harvest loss of potatoes, improve revenue generation, increase food availability, and maintain environmental sustainability. However, this solar drying technique can have some drawbacks. Abe-Inge et al. (2018) reported high browning in the solar-dried flour. They mentioned that the brown color of the solar-dried flour is associated with oxidative bleaching via the formation of brown pigments (melanoidins) and degradation of the original pigment of food materials.

2.7.2 Oven drying

Oven or hot-air drying is commonly used to dry fruits and vegetables. It is currently the most widely used technique in the post-harvest processing and/or preservation of agricultural products through drying (Dery, 2012). This method has been reported to yield more uniform, hygienic, and desired colored products that can be produced rapidly (Dery, 2012). According to Zhang et al. (2020), hot-air drying of potatoes resulted in potato flour with good gel stability and retrogradation properties conducive to making hot-processed products. Another study reported that hot air-dried native potato starch at 60 °C had higher relative crystallinity compared to samples dried using other methods, such as freeze-drying and radiofrequency drying (Zhu et al., 2019).

Moon et al. (2015) observed that the highest drying rate of potato slices in the oven dry was at 60 °C. Yadav et al. (2006) reported low viscosity for the potato flour produced by the oven-drying process. They also mentioned that this flour is useful in developing calorie-rich foods and food formulations for children with a higher solid content per unit volume. Zhang et al., 2020b) mentioned that oven drying made potato flour with good retrogradation, which is more conducive to forming hot processed products. Abe-Inge et al. (2018) stipulated that the oven drying method presents the best option considering the drying time, quality, and cost factors.

2.7.3 Freeze-drying

Known also as lyophilization, freeze drying is the process of freezing and sublimating water under special pressure and temperature conditions (Nowak & Jakubczyk, 2020b). Freeze drying is the best drying technology regarding product quality (Doymaz, 2012). During freeze-drying, there is no occurrence of heat damage because the material under processing remains frozen while drying occurs (Sugumarana et al., 2019). The technique preserves thermolabile biological properties of freeze-dried food products that would have otherwise been degraded or altered had they been subjected to drying by convection at higher temperatures (Nicanuru, 2016).

Freeze-drying also results in products with high hysteresis following rehydration and high viscosity (Haile et al., 2015). Ahmed et al. (2010) reported freeze-drying resulted in the production of sweet potato flour with higher L* (lightness) values and ascorbic acid content. A study on the effects of combined drying techniques on the properties of native potato flour revealed that freeze-dried exhibited the highest pasting viscosity compared to heat-treated samples (Zhu et al., 2019). In another study, freeze-drying yielded potato flour with good gel stability (Zhang et al., 2020a). Chen et al. (2017), in their study on the effects of drying processes on starch-related physicochemical properties of yam flour, demonstrated that freeze-drying had slower digestible (SDS) and resistant starches (RS) compared with those processed with other modern drying methods. Ríos-Ríos et al., 2016) recorded higher viscosity in the freeze-dried sample and suggested that it can be used as a thickener. Ikegwu et al. (2009) reported high swelling power for freeze-dried flour, which could be attributed to its higher carbohydrate, fat, and crude fiber content, which can absorb water molecules and swell. The higher swelling power obtained in freeze-dried potato flour indicates the high amylose content likely to be present in the starch granules (Chisenga et al., 2019). However, freeze-drying is time-consuming, with higher costs, because it involves freezing and the production of a vacuum (Guiné, 2018).

The composition of potato flour can vary depending on several factors, such as the variety of potatoes used, the production methods, and the degree of processing. Different researchers have reported the effect of different processing conditions on the chemical composition of potato flour, as summarized in **Table 2.2.**

Table 2.2: Chemical composition of potato flour prepared under different conditions.

Pre-treatments and processing methods	Moisture (%)	Protein (%)	Ash (%)	Fiber (%)	Carbohydrates (%)	Starch (%)	Resistant starch (%)	Amylose (%)	GI	Reference
Raw potato flour	9.69±0.07	8.68±0.04	4.05±0.07	-	-	77.45±0.25	45.25±0.28	24.15±0.14	-	(S. Yang, 2020)
Cooked (100°C, 30 min)	9.27±0.06	7.49±0.04	3.59±0.05	-	-	77.89±0.18	4.40±0.14	18.13±0.12	-	
Cooked-frozen (-18°C, 12 hours)	8.66±0.09	7.45±0.03	3.45±0.05	-	-	73.23±0.24	9.24±11	19.23±0.11	-	
Unblanched	9.99±0.01	11.55±0.07	8.50±0.70	9.35±0.07	67.37±0.52	-	-	-	-	(Kalamo et al., 2020)
Blanched (90°C, 5 min)	9.76±0.19	11.15±0.21	8.50±0.71	9.15±0.07	68.68±0.37	-	-	-	-	
Steaming + Oven Drying	5.55 ±0.00 to 8.26±0.06	7.68±0.02 to 10.04±0.00	3.71±0.11 to 5.03 ±0.03	- -	- -	66.65±2.40 to 73.14±1.32	- -	- -	- -	(Xu et al., 2019)
Untreated	-	10.2±01	4.1±0.1	-	85.6±0.1	69.8±0.3	-	18.6±0.3	-	(Kim & Kim, 2015a)
Pectinase treated	-	6.5±0.3	0.5±0.0	-	92.7±0.3	87.2±1.0	-	22.5±0.6	-	
Unbleached potato flour	10.95±0.09	9.95±0.21	8.50±0.71	9.35±0.07	70.01±0.59	84.23±2.08	-	14.72±0.12	-	(Klang et al., 2020)
Bleached potato flour	9.30±0.13	9.35±0.21	4.50±0.71	9.20±0.00	74.42±1.04	78.19±2.09	-	11.61±0.20	-	
No-irradiated potato flour.	10.50±0.10	10.27±0.05	2.53±0.02	5.44±0.08	70.38±0.24	-	-	-	-	(Alshawi, 2020)
Radiated (50 Gy)	9.59±0.05	9.60±0.01	3.35±0.01	5.56±0.01	70.38±0.03	-	-	-	-	
Radiated (150 Gy)	9.91±0.01	8.98±0.02	3.02±0.01	5.95±0.01	70.38±0.01	-	-	-	-	
Oven Drying (40° C, 48 hours)	8.7±0.3	-	-	-	-	73.5±0.2	-	-	-	(Bao et al., 2021)
Ethanol Drying	10.5±0.2	-	-	-	-	70.5±0.9	-	-	-	
Freeze Drying	8.7±0.3	-	-	-	-	75.5±0.5	-	-	-	
Sun Drying (3 days, 27-33 °C)	5.82±0.02	1.57±0.01	3.43±0.01	1.19±0.01	86.80±0.05	-	-	-	-	(Falade, 2016)
Solar Drying (5 days, 35-38°C)	6.12±0.20	1.55±0.01	3.02±0.02	2.70±0.01	84.56±0.09	-	-	-	-	
Vacuum-Freeze Drying	9.9±0.1	8.7±0.2	1.9±0.0	-	-	83.0±3.0	29.3±07	-	76.9	(QIU et al., 2019)
Hot air Drying	9.6±0.1	6.0±0.2	2.0±0.1	-	-	81.0±1.0	11.6±0.4		86.6	
Far-infrared (Heat pump drying)	9.9±0.3	6.4±0.2	1.9±0.0	-	-	80.0±0.6	6.3±0.6		88.5	
Air-Impingement Jet Drying	9.5±0.1	6.7±0.1	2.0±0.0	-	-	79.3±0.8	5.8±0.3		88.2	
Freeze drying	4.5±0.2 to 11.4±0.2	3.9±0.6 to 8.2±0.6	3.2±0.1 to 3.7±0.02	7.7±0.1 to 9.1±0.2	-	65±0.5 to 70±0.2	53.5±0.3 to 59.0±1	-	48±1 to 53±1	(Zhu & He, 2020)
Cooking (30 min) + freeze drying	-	-	-	-	-	-	0.81±0.6 to 2.0±0.7	-	131±1 to 140±1	

(-): Not determined

2.8 Potato flour functionality in food application

Because potato flour is rich in starch, it exhibits unique functional properties that make it ideal for specific product formulations (Avula & Singh, 2009). The properties of potato flour, however, may be affected by the preparation methods, the severity of heat treatment, the type of modification, and the presence of other components such as fiber, protein, etc. Changes in the structural characteristics of starches resulting from modifications or treatments may also be responsible for providing the potato flour with specific functionality (Xu et al., 2021). It is important to clarify that the functional properties of potato flour differ from those of starch because the additional components available in flour (non-starch polysaccharides, protein, fat, etc.) restrict the access of water to the starch granules (Avula & Singh, 2009; Yang et al., 2023). Jangchud et al. (2003) found that the sweet potato flour pasting parameters were not correlated to the pasting parameters of its purified starch.

2.8.1 Swelling power and Solubility index

When starchy products are exposed to a hot aqueous medium, the hydrogen bonds that hold the starch weaken, which allows the granules to absorb water and swell (van Rooyen et al., 2022). These parameters are desirable in the food system to improve the yield and consistency of foods. Factors such as amylose/amylopectin ratio and their molecular weight distribution determine the degree of swelling and solubility (Sasaki & Matsuki, 1998).

The swelling power is the measure of the ability of starch to imbibe water and swell. It reflects the extent of associative forces within the granules (Buckman et al., 2018b). A higher swelling index indicates higher associative forces (Buckman et al., 2018a). The bonding forces between the starches affect the swelling power (Kaur et al., 2023). Truong & Avula, 2014) mentioned that the swelling power of differently processed potato flours indicates the changes in the molecular organization within their starch granules. Wang et al. (2014) reported that swelling power is temperature dependent and is accompanied by solubilization of starch granule constituents. Flours with high swelling power and water absorption capacity are recommended as functional ingredients in producing viscous foods (Fennema & Tannenbaum, 1996). On the other hands, high-quality noodles are also defined as having a low thickness and high firmness. So, restricted swelling of flour for noodles making is a desirable trait as limited swelling stabilizes starch against shear action during cooking in water (Galvez et al., 1994). Flour with high swelling capacity and water absorption will not be recommended for noodles making as they increase viscosity (Park & Baik, 2002). The high swelling capacity makes noodles soft and less firm (Galvez et al., 1994).

The solubility index of a certain flour refers to the per cent soluble components leached out into the supernatant (Singh et al., 2005). Factors that may influence the solubility of starches are the source, swelling power, inter-associative forces within the amorphous and crystalline domains, and the presence of other components, such as phosphorous (Cahyo Kumoro et al., 2012). Dossou (2014) mentioned that high solubility could be due to increased hydrophilicity caused by increased polar components (sugars, organic acids, and soluble proteins) due to processing methods. High solubility could also be attributed to weak forces of attraction between the molecules of food material, leading to increased dissolution of the food material in water (Dossou, 2014). Practically, the solubility of starch is an important factor to be considered for product development, such as noodles. One of the qualities that define the quality of noodles is the cooking loss (Brennan et al., 2004), which refers to the amount of material separated from the product into the cooking water. High-quality noodles should have low cooking losses. The lower the solubility of flour, the lower the cooking loss.

Swelling and solubility are the results of the interaction between amylopectin, and the degree of their communication is affected by the amylose/amylopectin ratio and the properties of amylose and amylopectin in terms of molecular weight, distribution, degree, and length of branching, and conformation. Amylose-lipid complexes have been shown to inhibit swelling and dissolution (Swinkels, 1985).

2.8.2 Pasting characteristics of potato flour

Pasting properties indicate the extent of molecular degradation/changes, the degree of paste viscosity, and stability of starch (Avula et al. 2006). Native starch granules have a stable semi-crystalline structure, and their swelling in water is reversible at a lower gelatinization temperature. When the suspension temperature of the starch granule is higher than that of water, the starch granule will lose birefringence and crystallinity, and swelling occurs simultaneously. This is irreversible and called gelatinization (Alcázar-Alay & Meireles, 2015).

The gelatinization and pasting profiles of flour-water or starch-water mixtures are commonly monitored using a Rapid Visco Analyzer (RVA) (Balet et al., 2019 ; Higley et al., 2003). The RVA is a heating and cooling viscometer that measures the viscosity of a sample over a given period while it is stirred (Gamel et al. 2012). During the cooking process, the potato flour exhibits viscosity changes. Initially, as the flour is heated and stirred, the viscosity increases due to the swelling of starch granules and the release of starch molecules. However, with further heating and continued stirring, the viscosity decreases due to the breakdown of the starch structure. This property is called shear thinning, as the flour becomes less viscous under mechanical stress (Balet et al., 2019; Higley et al., 2003; Yuan et al., 2021).

An RVA profile of potato flour gelatinization is illustrated in **Figure 2.1**. It shows that the viscosity increases to a maximum, then decreases to a minimum value as the granules rupture (breakdown). Then the viscosity rises from the minimum to a final value, which is referred to as the setback, and the value of setback is related to the amylose content of the potato starch and the ease with which the starch is retrograded (Copeland et al., 2009). Results from the RVA amylograph test included peak viscosity (PV), trough viscosity (TV), breakdown viscosity (BD), final viscosity (FV) and setback viscosity (SB). The peak viscosity (maximum viscosity attained during the heating cycle) shows the ability of the starch granules in the flour to swell freely before they are physically broken down ((Aidoo et al., 2022). The trough viscosity (Tv), or holding strength or hot paste viscosity, or shear thinning, is when the flours are subjected to a period of constant temperature and mechanical shear stress (D.B. et al., 2015). The Breakdown viscosity (Bv) is the difference between the peak and trough viscosity after the heating ramp. The breakdown viscosity estimates the paste's resistance to disintegration in response to heat and shear (Kaur et al., 2007).The final viscosity (Fv) is the viscosity at the end of the heating. It indicates the ability of starch to form a viscous paste after cooking and cooling (Ashogbon & Akintayo, 2012a). The Setback viscosity (Sv) is the difference between the final viscosity during cooling and trough viscosity. It measures the retrogradation tendency of cooked flour paste upon cooling. It has been reported that flours with high setback viscosity will have a greater tendency to retrograde (Balet et al., 2019b).

Therefore, the RVA provides a convenient way of investigating the rheology of starch products. The Rapid Visco Analyzer (RVA) has been used to differentiate potato cultivars based on flour pasting properties”.

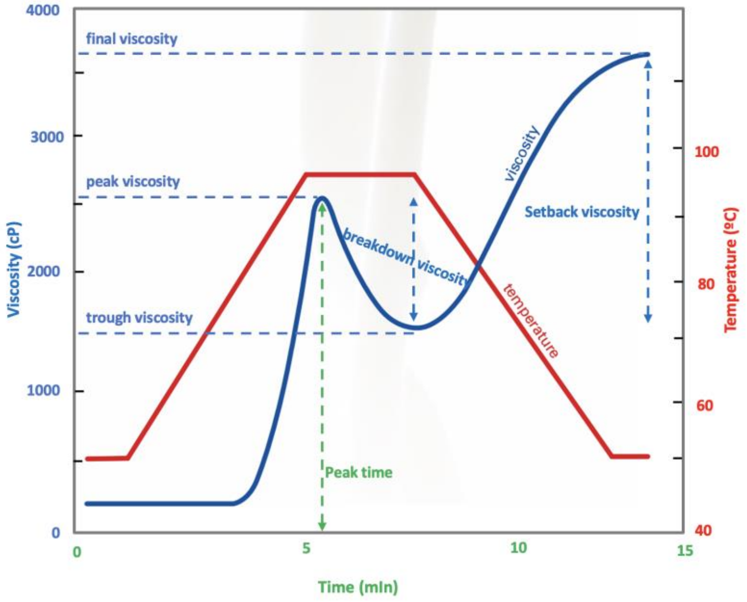


Figure 2.1: Typical sample RVA viscosity profile depicting time to gelatinization, time to peak, peak viscosity, breakdown, trough viscosity, total setback, and final viscosity (Higley et al., 2003).

The viscosity of flour plays a significant role in determining the texture, consistency, and overall quality of food products. In baking, for instance, flours with higher viscosity contribute to the development of structure and tenderness on bread, cakes and pastries (Wilderjans et al., 2013). The appropriate viscosity helps create the desired crumb structure, resulting in a soft, moist, pleasant texture. Avula & Singh, (2009)reported high paste viscosity in native potato flour and suggested that it can be used in formulations requiring high solids. High paste viscosities are desirable in flours used as thickeners (Ríos-Ríos et al., 2016). Low viscosity recorded in physically modified potato flour is desirable for preparing high-calorie food such as weaning foods (Wiesenborn et al., 1994; Avula & Singh, 2009).

2.9 Potato flour in food application

Compared with potato starch, potato flour has a wider range of nutrients and retains a better flavor and taste based on consumer appreciation (Rytel, 2012). Potato flour is widely used because of its rich nutrients and good taste (Akhobakoh et al., 2022). However, due to the lack of gluten protein, it is difficult to prepare bakery products such as bread, biscuits, and noodles with potato flour alone. It is incorporated in wheat flour and processed into various kinds of food (Misra & Kulshrestha, 2003; Nemar et al., 2015). Potato flour products also include potato bread (Liu et al., 2017), potato noodles (Javaid et al., 2018a), potato-cooked corn cake (Zeng et al., 2018), and potato cakes (Drakos et al., 2017).

Ijah et al. (2014) mixed potato flour with wheat flour at 0% to 10% substitution levels to make bread. The microbial and nutritional quality of normal bread and experimental bread were compared. The results showed that adding potato flour to wheat flour improved the nutritional value of bread. Sensory assessments indicated that consumers could accept bread with added potato flour. Similarly, Liu et al. (2017) studied the nutritional quality of steamed and baked breads containing 35 per cent potato powder from four potato varieties. Compared with traditional wheat varieties, potato-wheat buns and bread contained higher dietary fiber (1.87 to 2.21 times), potassium (2.68 to 3.36 times), vitamin C (28.56 to 50.21 times), and total polyphenols (1.90 to 3.33 times), and higher antioxidant activity (1.23 to 1.54 times). The researchers estimated the glycemic index of potato-wheat bread ranged from 61.20 to 67.36, lower than steamed bread (70.22) and baked bread (70.62).

Singh et al., (2020) conducted an experiment to develop potato flour-based cookies. They found that the sensory quality studies indicated that potato cookies in fresh condition (incorporated with 30% potato flour and 70% wheat flour) had maximum overall acceptability score of 8.05. Shami Sardar Vallabhbhai Patel et al., (2016) reported that cookies containing 30% potato flour scored high score for overall acceptability.

2.10 Utilization of potato flour in noodle's production

The global consumption of noodles is second after bread, a fast-growing sector of the pasta industry. This is because noodles are convenient, easy to cook, delicious, low cost, and have a relatively long shelf-life, which suits the busy lifestyle of students and the working busy population (Onyema et al., 2014; Sikander et al., 2017). The consumption of noodles is notably dominant amongst the youth population (Zahrul-lail, 2017). Nelson et al. (2009) reported that college students consumed instant noodles more than adults in other age groups.

Traditional noodles are made from common wheat flour, water, and/or salt through dough mixing, sheeting, and cutting (Fu, 2008). However, wheat flour, usually used to make instant noodles, is low in fiber and protein and poor in essential amino acids, especially lysine (Onyema et al., 2014; Dewettinck et al., 2008). Attempts have been made to solve this issue by substituting wheat noodles with various ingredients rich in fiber and protein, such as broken rice (Ahmed et al., 2015), oat flour (Guo et al., 2017), barley flour (Mitra et al., 2016), sweet potato flour (Montalbano et al., 2016), buckwheat flour (Ndayishimiye et al., 2016), carrot pomace flour (Tiony & Irene, 2021), soy flour (Rani et al., 2020), Oyster mushroom flour (Arora et al., 2018), red seaweed (Koh et al., 2022). Because of their lack of gluten protein, incorporating some of these ingredients will negatively affect the noodle quality, such as color, sensory and cooking characteristics. Nevertheless, an appropriate addition of these components provides an acceptable and improved nutritional value (Ahmed et al., 2015; Pu et al., 2017) and lower the allergenicity of wheat gluten (Ndayishimiye et al., 2016). Nawaz et al. (2019) reported that substituting wheat flour with other starches can effectively improve the quality of noodles (texture and microstructure) and provide health benefits for the consumer.

Having balanced nutrients and being a good carbohydrate source, adding potato flour in noodles can be an alternative to wheat flour. Nawaz et al. (2019b) suggested the addition of 40% potato flour to wheat four for acceptable physicochemical and functional properties of noodles. They also mentioned that increasing the amount of potato flour increased the redness (a*) and yellowness (b*) of the noodles. Xu Fen et al. (2017) studied the comprehensive nutritional values of noodles made from potato flour and reported that the content of protein, crude fiber, total starch, reducing sugar, vitamins B1, B2, B3, C, most mineral element, dietary fiber, and amino acids in potato noodles were higher than those in wheat noodles. Li Wang et al. (2016) reports that potato flour blended with a certain amount of wheat flour resulted in increased amylose content, lower swelling power and solubility, and greater gel strength, which are favorable properties for extruded noodles making. Pu et al. (2017) studied the effect of the ratio of potato flour to wheat flour on the mixing characteristics of the dough and the quality of the noodles. Their results showed that potato flour, instead of wheat flour, weakened dough strength but improved the resistance to degradation. The noodle samples' texture, cooking, sensory properties, and microstructure were also evaluated. The results showed that adhesion, elasticity, and sensory evaluation decreased with potato inclusion. However, the hardness, cooking yield, and optimal cooking time of the samples with potato powder content showed significant differences from the control samples. Environmental scanning electron microscopy (ESEM) confirmed the change in noodle microstructure, and the addition of potato flour affected the formation of the gluten network. Generally, noodles with less than 40% potato flour content were deemed acceptable. Li et al. (2018b) mentioned that potato flour improved the textural characteristics and cooking performance, such as broken rate and cooking loss of noodles. Yang (2020) reported that the brightness of noodles is normally reduced when other ingredients, such as potato flour, are incorporated into wheat to make noodles or pasta. These results agree with Desai et al. (2018) and Kowalczewski et al. (2015), who respectively reported a decrease in noodles' brightness after incorporating fish powder and potato juice into wheat flour. Potato flour has been reported to have a large amount of starch and many hydrophilic groups that facilitated the high absorption rate (Zaidul et al., 2007; Bártová et al., 2015). Bao et al. (2021) reported 40% of potato flour as the maximum amour in fresh noodles. Olivera-Montenegro et al. (2022), found 20% of potato flour was the best treatment to produce dry noodles.

Abdul Momin Sheikh et al. (2022) reported that noodles containing 30% potato flour were most preferred in terms of color.

Noodles made from potato flour and wheat flour differ from traditional wheat noodles. There is no gluten protein in potato flour, and the addition of potato flour results in the deterioration of noodles texture characteristics. Kang et al. (2017), reported that noodles made from potato flour exhibited lower values of textural characteristics obtain from the texture profile analysis. Replacement of wheat flour with gluten-free potato flour is likely to affect the noodle quality due to changes in protein quality, quantity, and starch quality (starch type and gelatinization degree). Juna Li et al. (2017), stated by utilizing the low gelatinization degree of flash-dried potato flour, desirable potato noodles were prepared with the ratio of potato flour up to 50%. Textural characteristics and cooking performance such as broken rate and cooking loss of flash-dried potato noodles were superior to these of the commercial potato flours (in the same amount) added noodles. Potato flour processing will therefore have an impact on the quality of noodles. Unfortunately, limited information on the properties of noodles made from potato flour processed in different ways.

CHAPTER THREE

PHYSICOCHEMICAL PROPERTIES OF POTATO FLOUR FROM THREE KENYAN POTATO VARIETIES PREPARED UNDER DIFFERENT PRE-TREATMENTS AND DRYING METHODS.

3.1 Introduction

Once harvested, potatoes are destined to be used for diverse applications with less than half of harvested potatoes are consumed fresh (FAOSTAT, 2008). The rest are processed into food products or food ingredients (FAO, 2008e). During processing, potatoes are transformed into products that are less bulky, less perishable, and less expensive to store and transport (Javaid et al., 2018a). Many products such as snacks (cookies) (Raigond et al., 2015), instant dried noodles (Javaid et al., 2018b), potato chips (Mariotti et al., 2015), and French fries (Yang et al., 2016) have been processed from potatoes. This has expanded the utilization window of potatoes in food and industrial applications.

Processing potatoes into flour produces not only a product that is nutritionally and functionally adequate but also shelf-stable (Pu et al., 2017b). Different processes are involved in potato flour preparation (Cui et al., 2018). Drying is one of the most used processes to dehydrate vegetables and fruits (Swanson & McCurdy, 2009). Processing potatoes into flour can affect the physicochemical properties of the flour depending on the choice and conditions of the processing methods (Falodun et al., 2019). Consequently, based on the target application, drying methods and pre-processing conditions are essential factors in determining the physical and chemical properties of potato flour. Therefore, the objective of this study was to determine the effect of different pre-treatments (blanching, boiling) and drying techniques (oven drying and freeze-drying) on the physicochemical properties of potato flour processed from three potato varieties.

3.2 Materials and Methods

3.2.1 Plant Material

Three popular potato varieties (*Solanum tuberosum* L.) grown in Kenya, namely, Shangi, Unica, and Dutch Robjin, were procured from an identified potato farmer in Nyandarua County. These varieties are the most consumed and used in diverse applications in industries (Abong et al., 2010). They also have high tuber yields (NPCK, 2017).

3.2.2 Percentage peel loss of potato tubers

One kilogram of cleaned potato tubers from each variety was weighed and peeled manually using a sharp stainless kitchen knife (Kulkarni et al., 1996). The peeled potatoes were then weighed. The percentage peel loss was calculated as shown in Equation 3.1. This was done in triplicate.

$$\textbf{Amount of peel (\%)} = \frac{\mathrm{WBP} - \mathrm{WAP}}{\mathrm{WBP}} \times 100 \qquad \textbf{Eq. (3.1)}$$

where, WBP: Weight of potatoes before peeling, WAP: Weight of potatoes after peeling.

3.2.3 Potato flour production

Various pre-treatments and drying methods were used to process potato tubers into flour as detailed in **Figure 3.1.**

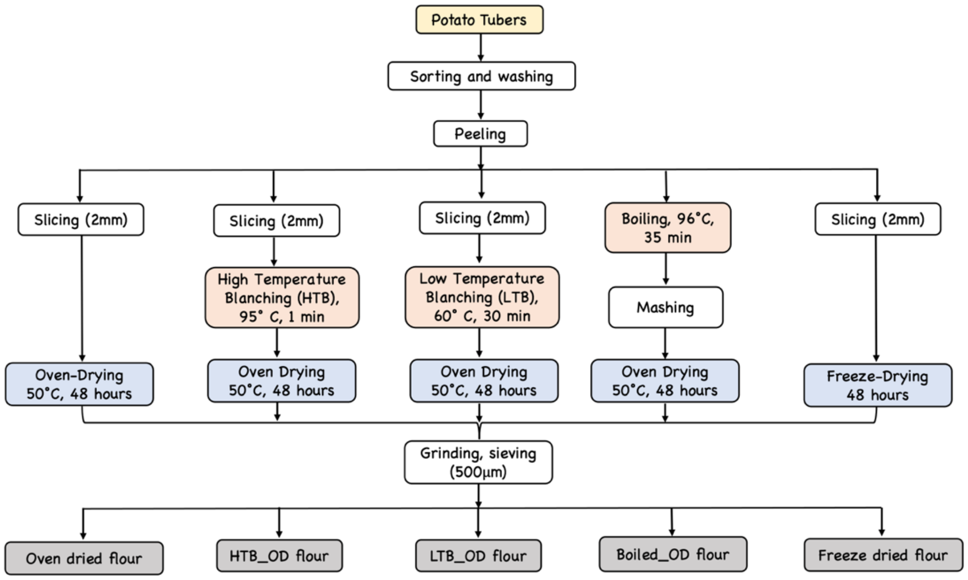


Figure 3.1: Schematic overview of the experimental set-up showing the five different flour types. OD: oven drying.

3.2.3.1 Oven drying (OD)

One kilogram of each of the three potato varieties was washed and manually peeled with a sharp stainless-steel knife. The peeled potatoes were cut into thin slices then kept in water containing 0.5% sodium metabisulfite for 5 min to prevent enzymatic darkening (do Nascimento et al. 2020). The thin slices were placed in an oven drier (Memmert UF 110 model, Schwabach, Germany) at 50 °C for 48 h with a constant air-flow rate of 2 m/s following a slightly modified methods reported by Iombor et al (2014). The dried slices were finely ground into flour using a blender (Vitamix 5200 Blender, professional-grade, Cleveland, OH, USA). The flour was passed through a 500 µm sieve, packed in transparent polyethylene zip-lock bags, and stored at room temperature until further analysis.

3.2.3.2 Blanching and Oven Drying

Blanched potato flours were prepared according to the method described by Sanjuán et al. (2005), with a slight modification. First, clean potato tubers were washed with tap water, manually peeled, and thinly sliced into 2 mm thickness. Next, potato slices were blanched in water at 60 °C [low temperature (LTB)] for 30 min and another portion at 95 °C [high temperature (HTB)] for 1 min, and immediately cooled in an ice water bath for 5 min. The blanched samples were then oven-dried as described in section 3.2.3.1, finely ground, sieved through a 500 µm standard sieve, packed in transparent polyethylene zip-lock bags, and stored at room temperature until further analysis.

3.2.3.3 Boiling and Oven Drying

Boiled potato flour was prepared using a method as previously described by Atikur Rahman (2015). Washed and peeled potato tubers were boiled in tap water at ~95 °C for 30 min and immediately cooled in an ice water bath for 5 min. Boiled potatoes were mashed using a conventional potato masher and placed into the oven drier (Memmert UF 110 model, Schwabach, Germany) at 50°C for 48 h. The dried mashed potatoes were ground, passed through a 500 µm standard sieve, and stored in polyethylene zip-lock bags at ambient temperature before further analysis.

3.2.3.4 Freeze-Drying (FD)

This was conducted as described by Mbondo et al. (2018), with slight modifications, using a freeze-dryer (Lyovapor L-200 Pro, BUCHI, Flawil, Switzerland). One kilogram of cleaned potato tubers was manually peeled and thinly cut into 2 mm thickness slices. Slices were placed in zip-lock bags pierced with holes and frozen in a deep freezer at −21 °C for 24 h before placing them in a freeze dryer. The holes allow for regulating temperature and pressure inside and outside the zip-lock bags during the drying process. Initial drying was carried out at −41 °C and 0.11 millibars, while final drying was carried out at −47 °C and 0.055 millibars. The freeze-drying process lasted 48 h in total. The freeze-dried potato slices were then collected, crushed, and milled in a blender before storage for further analysis.

3.2.4 Percentage yield of potato flour

One kilogram of each potato variety was washed and manually peeled with a sharp stainless-steel knife (Yang, 2020). After peeling, potatoes underwent pre-treatments to produce flour, as explained in section 3.2.3. The amount of flour from 1 kg of peeled potato was weighed. The percentage yield of potato flour was calculated as shown in Equation (3.2)

$$\textbf{Potato flour Yield (\%)} = \frac{\text{Weight of potato flour after Drying}}{\text{Weight of unpeeled potato}} \times 100$$

Eq. (3.2)

3.2.5 Physical Properties Determination

3.2.5.1 Potato flour color determination

Potato flour color was measured according to Pandey et al. (2022) using HunterLab's ColorFLex EZ spectrophotometer, USA. The instrument was first calibrated by using white and black tiles as the standards. Next, potato flour was tightly packed in an optically transparent glass cup and then covered with another opaque cover used as a light trap to prevent the external light from interfering with the sample cup. The clear glass containing the flour was then placed on the port. Light from the spectrophotometer was flashed on the sample, and the color intensity was recorded. The potato flour color was reported in terms of 3-dimensional color values on the following rating scale; Lightness L* ranges from (black [0] to light [100]), a* from (red [60] to green [- 60]), and b* ranges from (yellow [60] to blue [-60. The measurement was done in triplicate. The a* and b* values were used to calculate values for hue angle (H*) and chroma (C*) (Equations 3.3 and 3.4), two parameters that are used for describing the visual color appearance (Bernalte et al., 2003).

$$\mathbf{H^{*}=tan^{-1}(b/a)} \qquad \textbf{Eq. (3.3)}$$

$$\mathbf{C^{*}=(a^{2}+b^{2})^{-1}} \qquad \textbf{Eq. (3.4)}$$

3.2.5.2 True density

True density was calculated according to Deshpande & Poshadri (2011)**.** Toluene (C_7H_8) was used instead of water because it's absorbed by flour to a lesser extent. Approximately 1g of potato flour was filled in a 100 mL measuring cylinder containing toluene. The rise in toluene level was measured twice. The true density was calculated as indicated in Equation 3.5:

$$\textbf{True density (g/ml)} = \frac{\text{weight of flour sample}}{\text{rise in volume of toluene}} \qquad \textbf{Eq. (3.5)}$$

3.2.5.3 Bulk Density and Tapped Density

The bulk and tapped density of potato flour were determined according to the method described by Nep and Conway, (2011). Potato flour (10 g) was filled into a 100 mL measuring cylinder and, the bulk volume (V) was recorded. The bottom of the cylinder was continuously tapped (100 taps) on the platform continuously, and the volume was recorded as tapped volume (V_T). Bulk and tapped density were calculated as shown in Equations 3.6 and 3.7:

$$\textbf{Bulk Density } (B_D) = \frac{Mass}{V} \qquad \textbf{Eq. (3.6)}$$

$$\textbf{Tapped Density } (B_T) = \frac{Mass}{VT} \qquad \textbf{Eq. (3.7)}$$

3.2.5.4 Compressibility index

The compressibility index of potato flour was determined based on the bulk density and tapped density as described by Nep & Conway (2011) as shown in Equation 3.8.

$$\textbf{Compressibility index (\%)} = \frac{\text{Tapped density} - \text{Bulk density}}{\text{Tapped density}} \qquad \textbf{Eq. (3.8)}$$

3.2.5.5 Angle of repose

The angle of repose (θ) was determined by using the method described by Nep and Conway (2011). A funnel was mounted on a laboratory stand at a height of 2 cm from the bench. Potato flour (10 g) was weighed and allowed to flow through the funnel to form a pile at the base. The tip plug was removed, and the flour was allowed to pass through the orifice. The height and diameter of the flour heap were measured. The angle of repose, θ, was calculated as shown in Equation 3.9:

$$(\theta) = \tan^{-1}\left(\frac{H}{R}\right) \qquad \text{Eq. (3.9)}$$

Where ***H*** is the height of the cone formed after the flow was complete and ***R*** is the radius of the cone.

3.2.6 Proximate composition of potato flour

3.2.6.1 Moisture content

The moisture content was determined as described by the Association of Official Agricultural Chemists AOAC (2000). The determination of the moisture content of potato flour was performed gravimetrically according to the hot air oven method. Approximately 2 g of potato flour was weighed in triplicates and dried in an oven at 105 °C overnight and cooled in a desiccator. The dried samples were then weighed to calculate the moisture content as shown in Equation 3.10.

$$\%\ \text{Moisture} = \frac{(W1-W2)}{W1} \times 100 \qquad \text{Eq. (3.10)}$$

Where: W1 is the initial weight (g) and W2 the final weight (g).

3.2.6.2 Protein determination

Protein content was determined using the semi-micro Kjeldal AOAC method 976.05 (AOAC, 2000). Two grams of the potato flour sample were accurately weighed in triplicate into a digestion flask together with a combined catalyst of 5 g of K_2SO_4 and 0.5 g of (Sulfate copper) $CuSO_4$ and 15 mL of concentrated (Sulfuric acid) H_2SO_4. The mixture was heated in a fume chamber (400°C) till the digest color become blue.

The blue color signified the end of the digestion process. The digest was then cooled, transferred to a 100-mL volumetric flask, and topped up to the mark with deionized water. A blank digestion with the catalysts was also run. Approximately 10 mL of diluted digest was transferred into a distilling flask and washed with about 2 mL of distilled water. Approximately 15 mL of 40% NaOH was then added to make the digestion solution alkaline, and this was also washed with 2 mL of distilled water. 25 mL of boric acid was placed in a conical flask then few drops of mixed indicator was added, and the flash was fixed at the receiving end of the distillation apparatus to collect the distillate. The burner was placed under the boiling flask of the distillation apparatus and was adjusted so that 40-50 ml of the distillate was collected in 15 minutes. The distillate was titrated using 0.02N HCl until the colour changes to orange which signifies the endpoint. The crude protein was calculated as follows:

$$\textbf{\% Nitrogen} = (V_1 - V_2) \times N \times f \times 0.014 \times \frac{100}{v} \times \frac{100}{s} \qquad \textbf{Eq. (3.11)}$$

Where: **V_1** is the titer for the sample in ml, **V_2** is the titer for blank in ml, **N** is the normality of the standard HCl solution (0.02), **f** is the factor of the standard HCl solution, **v** is the volume of diluted digest taken for distillation (10 mL), **s** is the weight of sample taken (1 g). Protein was calculated as follows:

$$\textbf{\% Protein} = \% \, Nitrogen * 6.25 \qquad \textbf{Eq. (3.12)}$$

3.2.6.3 Fat content analysis

Determination was done using the Soxhlet method 920.85-32.1.13, (AOAC, 1995). The extraction flask was heated to constant weight at 105°C for 1 h then cooled to room temperature in a desiccator. Approximately 5g of potato flour sample was weighed accurately into extraction thimbles and the initial weight of extraction flasks was taken. The thimble was placed in an extraction apparatus fat extraction was done using ethyl ether in the Soxhlet apparatus for 8 hours. 150 ml of extraction solvent (petroleum ether) was added into the round bottom flasks. The extraction solvents were rota-evaporated, and the fat extracted dried in a hot air oven (70°C) for 15 minutes before the final weight of flasks with extracted oil was taken.

$$\% \text{ Fat} = \frac{\text{Weight of extracted Fat}}{\text{Weight of the sample}} \times 100 \qquad \textbf{Eq. (3.13)}$$

3.2.6.4 Ash determination

The ash content was determined using the official method of the AOAC (1995). Two grams of each potato flour sample were accurately weighed in triplicate into a weighed crucible and incinerated in a muffle furnace at 600°C for about 6 hours. The crucible was removed and cooled in a desiccator and reweighed.

$$\% \text{ Ash} = \frac{(\text{Weight of crucible+Ash}) - (\text{Weight of crucible})}{\text{Weight of the sample}} \times 100 \qquad \textbf{Eq. (3.14)}$$

3.2.6.5 Crude fiber determination

The method of Joslyn, (1970) was used for crude fiber determination. Two gram of defatted potato flour was hydrolyzed in a conical flask with 200 ml of 1.25% H_2SO_4 for 30 minutes, and then filtered under suction, washed with hot distilled water, and boiled again for another 30 minutes with 200ml of 1.25% NaOH. The digested samples were washed with 1%HCL to neutralize the NaOH several times with hot distilled water. The residue collected was put into a weighed crucible and dried at 100°C for 2 hours in an air oven. It was cooled and weighed. The % crude fiber was calculated using the equation below:

$$\% \text{ Crude fiber} = \frac{\text{Loss in weight after digestion}}{\text{Weight of the sample}} \times 100 \qquad \textbf{Eq. (3.15)}$$

3.2.6.6 Carbohydrate determination

The carbohydrate content was determined by calculation (by difference) according to (Uraku et al., 2015).

% Carbohydrate = 100 − (% moisture +% crude fiber +% ash +% crude fat +% crude protein)

3.2.7 Mineral composition of potato flour

The contents of iron (Fe), zinc (Zn), magnesium (Mg), potassium (K), phosphorus (P), and calcium (Ca) in potato flour were determined by the AOAC (2000) method. After preparative steps, which included ashing 5 grams of potato flour, dissolving the ash in 100 ml of 0.05 N nitric acid solution followed by a series of filtration, the minerals were quantified using atomic absorption spectrophotometers (AAS) (Shimadzu AA-7000 series, Japan). Mineral standards were used to quantify the minerals in potato flour. Mineral determinations were done in triplicate for each flour type.

3.2.8 Sugar content

The concentrations of glucose, fructose, and sucrose were determined using the method described by Abong et al. (2011) with slight modifications. Five grams of potato flour were weighed into round-bottom flasks, and 10 mL of ethanol was added and mixed. It was then refluxed at 100 °C for one hour before being filtered through filter paper (Whatman number. 2). A rotary vacuum evaporator was used to evaporate the solvent until it was dry. A mixture of 2 mL deionized water and 2 mL acetonitrile was used to reconstitute the dried samples in a ratio of 50:50 (v/v). The samples were microfiltered (0.45-μm pore size) before injecting 20 μL into an Ultra-Flow Liquid Chromatography (Shimadzu Nexera UFLC) fitted with a SIL-20A HT prominence autosampler, refractive index detector-20A, and an LC-20A pump. The sugars were separated by isocratic elution with acetonitrile and deionized water (75:25), then pumped through a normal phase Ultisil NH_2 column with a 6 × 250 mm internal diameter at a flow rate of 1.8 mL/min. The CTO-10ASvp column-oven temperature was set at 40 °C. Each sample was measured in triplicate using standard fructose, glucose, and sucrose solutions, and the free sugar concentration was expressed in mg/100g.

3.2.9 Statistical analysis

Each result is an average of three determinations and is expressed as mean ± standard error. Analysis of variance and Tukey’s test were performed to compare means using

SPSS 18.0 (SPSS Inc., Chicago, USA) software at a significance level of 0.05%. Pearson correlation analysis was performed using the R language (version 3.2.1) at the level of p<0:05, p<0:01, and p< 0:001 for significant, quite significant, and highly significant differences, respectively.

3.3 Results and Discussion

3.3.1 Percentage Peel Loss (%)

As shown in **Figure 3.2**, the Dutch Robjin variety recorded the highest percentage of peel loss (25%), while Unica showed the least (8%). This difference could be attributed to the morphological differences between the varieties, especially the number and depth of eyes (Abong et al., 2009). The Dutch Robjin variety had more eyes as compared to the other varieties. The more eyes the tuber has, and the deeper they are, the greater the peeling loss (Evelyne et al., 2021).

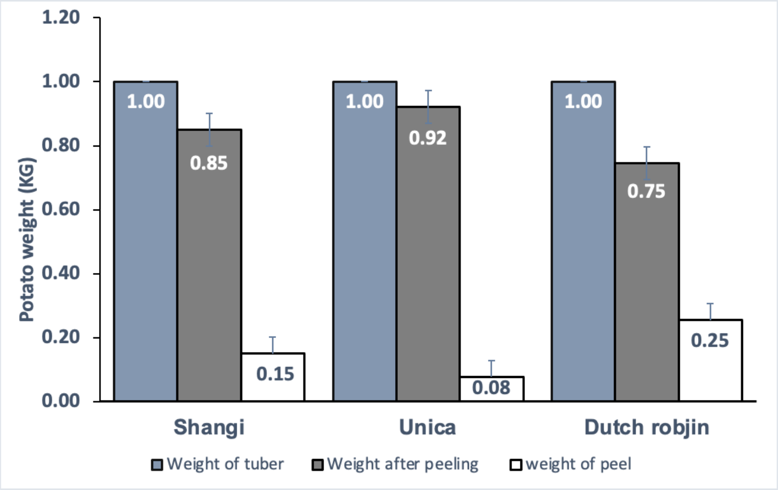


Figure 3.2: Percentage peeling loss of the three varieties

3.3.2 Percentage Yield of Potato Flour

Potato flour yields from the different potato varieties as affected by pre-treatments and drying methods are shown in **Table 3.1**.

Table 3.1: The percentage yield of potato flour from three varieties as affected by pre-treatments and drying methods.

Treatment	Shangi (%)	Unica (%)	Dutch Robjin (%)
Oven-Drying (OD)	18.48±0.01^{a}	17.31±0.03^{a}	22.50±0.04^{a}
Blanching (60°) _OD	17.25±0.12^{b}	16.31±0.06^{d}	20.83±0.05^{b}
Blanching (95°) _OD	15.77±0.13^{d}	16.01±0.03^{e}	20.42±0.04^{c}
Boiling_OD	16.50±0.06^{c}	16.83±0.02^{c}	19.44±0.07^{d}
Freeze-Drying (FD)	18.70±0.23^{a}	17.64±0.06^{a}	22.99±0.08^{a}

Results are the means of triplicate determinations ± standard error. Mean values with different letters (a, b, c, d, e) in the same column indicate significant differences based on the Tukey test of significance ($p < 0.05$, n=3). OD-Oven Drying

There was a significant difference in the yield of potato flour obtained from the different processing methods. Boiling followed by oven drying resulted in the lowest flour yield in all three varieties. This might be associated with the leaching of starch during boiling. On the other hand, Dutch Robjin resulted in the highest flour yield in all the processing conditions. This might be attributed to its high specific gravity and dry matter compared to the other varieties (NPCK, 2017 and Krishnan et al., 2010). There was no significant difference in yields of the flour obtained from oven-drying and freeze-drying.

3.3.3 Color of Potato Flour

The color parameters of the potato flour varied greatly depending on the different pre-treatments and drying methods. Similar trends were observed in different varieties suggesting that color parameters can be generalized across different potato varieties, enhancing the practical applicability of our findings. Only results for the Shangi variety are shown below (**Table 3.2** and **Figure 3.3**). Results for Dutch Robjin and Unica varieties can be found in **Appendix II** for reference.

Table 3.2: Color parameters of potato flour from different treatments and drying conditions.

Samples	L*	a*	b*	Chroma	Hue
Oven drying (OD)	90.86 ± 0.01^{b}	0.31 ± 0.01^{d}	15.19 ± 0.01^{d}	15.19 ± 0.01^{d}	1.55 ± 0.01^{a}
Blanching (60°C) _OD	84.17 ± 0.01^{c}	1.43 ± 0.01^{c}	11.66 ± 0.01^{e}	11.75 ± 0.01^{e}	1.45 ± 0.01^{c}
Blanching (95°C) _OD	82.36 ± 0.01^{d}	1.71 ± 0.01^{b}	20.72 ± 0.01^{b}	20.79 ± 0.01^{b}	1.49 ± 0.01^{b}
Boiling_OD	80.38 ± 0.01^{e}	4.07 ± 0.01^{a}	25.90 ± 0.01^{a}	26.22 ± 0.01^{a}	1.42 ± 0.01^{d}
Freeze-drying (FD)	92.86 ± 0.01^{a}	-0.65 ± 0.01^{e}	16.34 ± 0.01^{c}	16.35 ± 0.01^{c}	-1.53 ± 0.01^{e}

Results are the means of triplicate determinations ± standard error. Mean values with different letters (a, b, c, d) in the same column indicate significant differences based on the Tukey test of significance ($p < 0.05$, n = 3). OD-Oven Drying. **L***: lightness of the color and ranges from 0 to 100; **a***: This represents the position of the color on the green to red axis; **b***: represents the position of the color on the blue to yellow axis

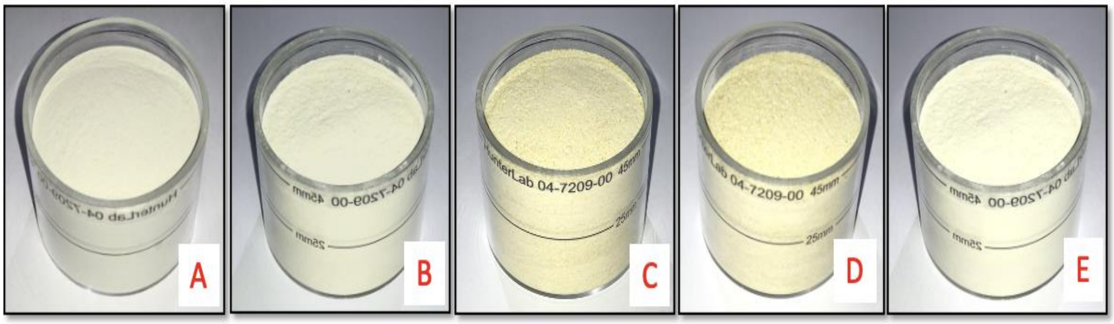


Figure 3.3: Potato flour prepared from different pre-treatments and drying methods. (A) Oven drying; (B) blanching at low temperature (60 °C); (C) blanching at high temperature (95 °C); (D) boiling; (E) freeze drying. Note that these images are the Shangi variety.

Freeze-dried flour recorded the highest value of L* (92.86) and the lowest a* (−0.65) value. A higher L* value indicates white flour and a lower browning index (Krishnan et al., 2010). Freeze-drying involves freezing the foods at very low temperature before drying. This low temperature prevents polyphenol oxidase induced browning. By keeping temperature low, freeze drying prevents or significantly reduces this reaction, preserving the white color (Krishnan et al., 2010). Flours obtained from boiling followed by oven drying had the lowest L* value, and highest a* and b* values. Murayama et al. (2015) reported that a higher b* value indicates higher yellow color due to prolonged boiling or steaming during the preparation of potato flour. These would affect the final color of food products (Olatunde et al., 2016). The higher a* value in boiled flour could have been due to the more prolonged exposure of samples to heat (Dery, 2012). The hue angle (H*) was negative for freeze-dried flour. A negative value of the hue angle (H*) indicates that white was dominant in the sample. The Chroma value is a measure of the color purity of a material (Bolade & Oni, 2015). It defines the color intensity of materials, so the higher the value of chroma is, the more intense the color (Vasconcelos et al., 2015). Freeze drying, oven drying, and LTB_OD, produced flour with the lowest chroma values compared to the high-temperature treatments (Boiling_OD and HTB_OD). Similar results were obtained by do Nascimento and Canteri (2018b) on potato flour. A low value of chroma and a high value of lightness of flours are desired by consumers (Alabi et al., 2016). Therefore, freeze-dried flour would be more acceptable to consumers compared to flour from other processing methods.

3.3.4 Bulk, Tapped and True Density

There was a significant difference ($p < 0.05$) in the bulk density of the potato flour prepared under different conditions (**Table 3.3**). It is noteworthy that all three potato varieties exhibited similar patterns in our experimental results. Therefore, our conclusions are not limited to a single potato variety but are likely to hold for a broader range of varieties. Results for the Shangi variety are shown below, while results for Dutch and Unica varieties can be found in **Appendix III**.

The bulk density varied from 0.49 $g.mL^{-1}$ for freeze-dried flour to 0.91 $g.ml^{-1}$ Boiling_OD. Bulk and tapped densities give information on the particle packing and arrangement, and the material's compaction profile (Mirhosseini & Amid, 2013). They are influenced by particle size, particle size distribution, attractive interparticle forces, and particle shape (Singh et al., 2010).

Table 3.3: Bulk density, tapped density, and true density of potato flour prepared under different pre-treatment and drying conditions.

Samples	Bulk Density (g/mL)	Tapped Density (g/mL)	True Density (g/mL)
Oven drying (OD)	0.70 ± 0.01^{c}	0.97 ± 0.02^{b}	1.65 ± 0.01^{a}
Blanching (60°C) _OD	0.77 ± 0.02^{b}	1.01 ± 0.01^{a}	1.64 ± 0.01^{a}
Blanching (95°C) _OD	0.87 ± 0.02^{a}	1.02 ± 0.01^{a}	1.65 ± 0.00^{a}
Boiling_OD	0.91 ± 0.02^{a}	1.03 ± 0.01^{a}	1.65 ± 0.01^{a}
Freeze drying (FD)	0.49 ± 0.01^{d}	0.70 ± 0.01^{c}	1.46 ± 0.02^{b}

Results are the means of triplicate determinations ± standard error. Mean values with different letters (a, b, c, d) in the same column indicate significant differences based on the Tukey test of significance ($p < 0.05$, n = 3). OD, oven drying.

The low bulk density of the freeze-dried flour might have mainly occurred because of the increased volume rather than the mass. During freeze-drying, the volume of the potato increases due to the conversion of ice to water vapor, the overall mass of the potato slices decreases because the water is being removed as vapor (Nowak & Jakubczyk, 2020a). Since the ice contains water, and this water is leaving the potato as gas, the mass of potato is reduced resulting in low bulk density. The removal of water leaves a structure with gaps where the ice crystal used to be. This sponginess and porous nature lead to an expansion in volume. This produce flour with reduced weight and making it lightweight and easy to store (Mirhosseini & Amid, 2013).

Tapped density is determined to correct the fluctuation of the total volume of interparticle voids during transportation, drying, and packing processes. It is the maximal packing produced under the impact of an externally applied force. It indicates the volume of the mass of the sample after tapping the container to cause a closer packing of particles. Consequently, freeze-dried potato flour was more porous, since it had the lowest tapped density. This is because freeze-dried powder granules have small particles that can agglomerate to form a clumpy powder, thus producing more voids between them (Hasmadi, 2021). Flours with low bulk density tend to have high viscosity, texture, and consistency that allow for easy consumption and digestibility (WHO, 2003). Boiling_OD and HTB_OD, flours showed the highest tapped density, thus indicating the least porosity among all samples. The high bulk density of flour suggests its suitable mixing ability during blending process and food preparations, as reported by Chandra et al. (2015). In addition, these flours do not take up much space and decrease packaging costs. This study indicated that pre-treatments and drying methods significantly ($p < 0.05$) influenced the true density of potato flour. The true density of the flours varied from 1.46 g/mL to 1.65 g/mL. Freeze-dried flour had the lowest true density compared to other treatments. This could be attributed to the ice sublimation during freeze-drying which creates more pores within the samples (Oikonomopoulou et al., 2011).

3.3.5 Compressibility Index (CI) and Angle of Repose

The effects of different pre-treatments and drying methods on the compressibility index and angle of repose of potato flour are shown in **Table 3.4**. The different flours showed different compressibility indices and angles of repose, which indicate different flow behavior. Similar trends were observed in different varieties indicating their comparable performance in terms of compressibility Index and Angle of repose. Results for the Shangi variety are shown below, while results for Dutch and Unica varieties are displayed in the appendices section **(Appendix IV).**

Table 3.4: Compressibility Index (CI) and angle of repose of potato flour.

Samples	CI (%)	Angle of Repose (°)	Flow Description	Type of Flour
Oven drying (OD)	27.73 ± 0.92^{b}	30.57 ± 0.29^{b}	Poor	Cohesive
Blanching (60 °C) _OD	21.79 ± 0.52^{c}	28.94 ± 0.12^{c}	Fair to good	Non-cohesive
Blanching (95 °C) _OD	16.31 ± 0.61^{d}	28.89 ± 0.17^{c}	Good to excellent	Free-flowing (non-cohesive)
Boiling_OD	13.48 ± 1.78^{d}	28.01 ± 0.28^{d}	Good to excellent	Free-flowing (non-cohesive)
Freeze-drying (FD)	31.56 ± 1.07^{a}	32.40 ± 0.12^{a}	Very poor	Cohesive

Results are the means of triplicate determinations ± standard error. Mean values with different letters (a, b, c, d) in the same column indicate significant differences based on the Tukey test of significance ($p < 0.05$, n = 3). OD, oven drying. Flow behavior of potato flour was described according to a method developed by Carr, (1965).

The compressibility index (CI) ranged from 13.48% to 31.56%. Boiling_OD exhibited the lowest CI, while freeze-drying, the highest. Boiling_OD and HTB_OD showed a lowest compressibility index meaning that the flour has good flowability characteristics. Conversely, oven-drying and freeze-drying had the highest compressibility indexes indicating poor flow behavior (cohesiveness). Flours with good flow behavior are suitable for easier mixing, transport, and other manufacturing manipulations (Abe-Inge et al., 2018).

The highest angle of repose was recorded for freeze-drying treatment while Boiling_OD and HTB_OD showed the lowest angle of repose. The angle of repose was significantly ($p < 0.05$) influenced by the pre-treatments and drying methods, thus affecting the flour behavior. The angle of repose measures the flour's resistance to the flow under gravity due to frictional forces resulting from the surface of the granules (Onunkwo, 2010). A high angle of repose implies a decrease in flowability characteristics (Mirhosseini & Amid, 2013). The angle of repose is important for designing processing, storage, and conveying systems of particulate materials. A high angle of repose is associated with a fine and sticky material that is not free flowing. In contrast, materials with a low angle of repose are highly flowable and can be transported using little energy (Mirhosseini & Amid, 2013).

3.3.6 Proximate composition

The results of the proximate composition analysis of flours from 3 potato varieties are presented in **Table 3.5**. Potato flours moisture content ranged from 7.37% to 10.79%, which is acceptable for commercial flours. According to Simsek (2015), flour with a moisture content greater than 14% does not maintain its stability at room temperature. Various factors can affect moisture content, including drying methods, drying times, and storage conditions (Van Hal, 2000). Potato flour with low moisture has a longer shelf life because it inhibits microbial growth and chemical reactions (Falodun et al., 2019).

Table 3.5: Proximate composition of potato flour from three varieties processed using different methods.

Variety	Parameters	Oven Drying	LTB_OD	HTB_OD	Boiling_OD	Freeze Drying
Shangi	Moisture (%)	10.15 ± 0.06^{b}	10.33 ± 0.02^{a}	$9.85\pm0,03^{c}$	8.24 ± 0.02^{d}	10.44 ± 0.03^{a}
	Protein (N x 6.25)	9.53 ± 0.09^{b}	9.26 ± 0.12^{b}	6.66 ± 0.14^{c}	6.41 ± 0.08^{c}	10.17 ± 0.10^{a}
	Ash (%)	4.33 ± 0.01^{a}	4.22 ± 0.06^{a}	3.50 ± 0.05^{c}	4.01 ± 0.01^{b}	4.08 ± 0.05^{b}
	Fibre (%)	1.51 ± 0.02^{c}	1.55 ± 0.02^{bc}	1.71 ± 0.02^{ab}	1.85 ± 0.06^{a}	1.51 ± 0.09^{c}
	Fat (%)	0.32 ± 0.03^{a}	0.32 ± 0.03^{a}	0.09 ± 0.01^{b}	0.11 ± 0.01^{b}	0.36 ± 0.02^{a}
	Carbohydrates (%)	74.15 ± 0.18^{c}	74.32 ± 0.21^{c}	78.69 ± 0.22^{b}	79.40 ± 0.05^{a}	73.43 ± 10^{d}
Unica	Moisture (%)	10.79 ± 0.03^{a}	8.91 ± 0.12^{c}	7.80 ± 0.18^{d}	9.45 ± 0.01^{b}	9.88 ± 0.04^{b}
	Protein (N x 6.25)	7.38 ± 0.23^{b}	7.85 ± 0.05^{b}	6.85 ± 0.01^{c}	5.67 ± 0.23^{d}	8.62 ± 0.02^{a}
	Ash (%)	3.06 ± 0.01^{c}	3.53 ± 0.10^{b}	3.87 ± 0.03^{b}	2.80 ± 0.14^{d}	4.50 ± 0.06^{a}
	Fiber (%)	1.61 ± 0.04^{a}	1.62 ± 0.03^{a}	1.49 ± 0.21^{b}	1.14 ± 0.01^{c}	1.53 ± 0.32^{b}
	Fat (%)	0.20 ± 0.01^{b}	0.24 ± 0.09^{b}	0.22 ± 0.10^{b}	0.12 ± 0.01^{c}	0.35 ± 0.01^{a}
	Carbohydrates (%)	80.85 ± 0.06^{a}	77.85 ± 0.15^{c}	79.77 ± 0.11^{b}	80.82 ± 0.12^{a}	77.12 ± 0.41^{c}
Dutch Robjin	Moisture (%)	9.35 ± 0.02^{a}	7.91 ± 0.22^{c}	7.37 ± 0.03^{c}	8.33 ± 0.02^{b}	8.18 ± 0.24^{b}
	Protein (N x 6.25)	7.98 ± 0.07^{b}	7.72 ± 0.11^{b}	6.55 ± 0.12^{c}	5.29 ± 0.15^{d}	8.86 ± 0.02^{a}
	Ash (%)	3.34 ± 0.31^{a}	2.84 ± 0.03^{c}	3.21 ± 0.22^{ab}	2.94 ± 0.03^{c}	3.11 ± 0.41^{b}
	Fibre (%)	1.32 ± 0.01^{c}	1.71 ± 0.02^{b}	0.97 ± 0.32^{d}	0.75 ± 0.05^{e}	2.01 ± 0.16^{a}
	Fat (%)	0.16 ± 0.04^{c}	0.21 ± 0.06^{b}	0.16 ± 0.01^{c}	0.07 ± 0.01^{c}	0.25 ± 0.02^{a}
	Carbohydrates (%)	79.85 ± 0.21^{c}	79.55 ± 0.01^{c}	81.74 ± 0.14^{b}	82.62 ± 0.33^{a}	77.59 ± 0.21^{d}

The results are the average of three measurements ± standard error. Different letters (a, b, c, d) in the same row indicate a significant difference ($p< 0.05$, n=3). OD (Oven Drying), LTB_OD (low-temperature blanching, 60°C for 30 minutes), HTB_OD (High-temperature blanching, 95°C for 1 minute.

Different processing treatments significantly ($p<0.05$) influenced the protein content. This trend was observed of all the varieties. Freeze-dried flour exhibited the highest protein content (10.17%) for Shangi, (8.62%) for Unica and (8.86%) for Dutch. Freeze drying preserves protein content more than other methods because it uses low pressure and temperature, which preserves cellular structure (Falodun et al., 2019). Yang (2020) and Vaitkevičienė (2019) reported higher values for freeze-dried potato flour of 13.06% and 12.1%, respectively, which were higher than what reported in this study. This difference might be attributed to the varieties used during flour preparation (Lingling et al. 2018). The lowest protein values in all varieties were reported in Boiling_OD and HTB_OD potato flours, which could be due to protein denaturation during exposure to high temperature followed by leaching during the cooking and blanching pre-treatments, as reported by Hidayat & Setyadjit (2019). A study by Lakra & Sehgal (2011) observed that protein content of boiled potato flour was 9.5%, which is higher to our findings. This might be attributed to the time of exposure to heat (cooking time), temperature or the initial composition of potatoes (Chen et al 2020).

Ash content differed significantly among the five treatments. The ash content was higher in oven-dried and freeze-dried potato flour and low in HTB_OD and boiling potato flour. A similar trend was observed in all the varieties. Rahman et al. (2015) reported similar results of 3.59 % ash content for potato flour, while Hidayat & Setyadjit (2019) revealed a range of 3.17 to 4.31% in blanched potato flour. Higher values ranging from 5.1 to 6.7% were reported by Vaitkevičienė (2019) for freeze-dried potato flour. The higher the ash content, the higher the mineral content of the flour.

The crude fiber ranged from 0.75 to 2.01 % depending on the processing methods. This variability was also observed in different varieties. In all varieties, the highest fiber content was recorded in Boiling_OD and HTB_OD flour. Cooking potatoes has also been reported to increase their dietary fiber content (Dhingra et al., 2012; Yang, 2020). Blanching and cooking at high temperatures alter starch compositions and ratios (rapidly digestible starch, resistant starch, and slowly digestible starch). Starch gelatinization occurs when potatoes are cooked at high temperatures, converting most of it into rapidly digestible starch. When the same potatoes are cooled, some rapidly digestible starch is converted to resistant starch by retrogradation, increasing the fiber content (Raigond et al., 2020). Fiber facilitates bowel transit, reduces calorie consumption, and reduces diabetes incidence (Falodun et al., 2019). Moreover, it reduces glucose absorption, lowering blood sugar levels and carbohydrate metabolism (Brennan et al., 2004). Consequently, flours processed by Boiling_OD and HTB_OD should have a lower carbohydrate metabolism and lower blood sugar effects.

It was found that the fat content of potato flour was very low (< 0.5% in all cases). This was observed in all the varieties studied. The fat content of freeze-dried and oven-dried flours significantly differed from the heat-treated potato flours such as

Boiling_OD and HTB_OD flours. The high cooking temperatures lead to lipid solubilization resulting in their loss into the cooking water. Triasih & Utami (2020) reported that the fat solubilization and damage level varies greatly depending on temperature and processing time. The low-fat content of potato flour recorded in this study is desirable as it reduces the risk of rancidity due to lipid oxidation reaction during storage (Buckman et al., 2018).

The carbohydrate content of potato flours ranged from 73.43 % to 82.62 % from one variety to another and depending on the processing methods used. Freeze-dried potato flour had the lowest carbohydrate content while HTB_OD and Boiling_OD potato flour recorded the highest. The increase in the carbohydrate in HTB_OD and Boiling_OD potato flour could be due to the lower levels of other proximate components (protein, ash, fiber). Gregory & Blessing, (2010) stated that this is probably due to the heat involved which reduced other components as a result of denaturation and leaching leading to an increase in carbohydrate content. The carbohydrate should normally increase since its obtained by subtracting other components from 100 (Nsa et al., 2011). HTB_OD and Boiling_OD potato flour could be a good source of energy in food formulation.

3.3.7 Sugar content

Potato flour differed greatly in sugar content, with sucrose being the most prevalent sugar, followed by glucose and fructose. This trend was observed for all the three varieties as shown in **Table 3.7**. A varietal difference was observed in terms of sugars content. The Dutch Robjin variety exhibited the highest sugar content. This difference could be attributed to genotype differences as reported by Evelyne et al. (2021).

Table 3.6: Sugar contents of potato flour from three varieties processed using different methods.

Variety	Parameters	Oven Drying	LTB_OD	HTB_OD	Boiling_OD	Freeze Drying
Shangi	Glucose (mg/100g)	11.55 ± 0.17^{b}	10.81 ± 0.13^{c}	8.50 ± 0.11^{d}	6.81 ± 0.19^{e}	15.73 ± 0.49^{a}
	Fructose (mg/100g)	28.21 ± 0.22^{b}	20.70 ± 0.43^{c}	14.54 ± 0.41^{d}	10.36 ± 0.27^{e}	32.00 ± 0.60^{a}
	Sucrose (mg/100g)	38.31 ± 0.56^{b}	31.69 ± 1.33^{b}	18.03 ± 0.26^{c}	15.34 ± 0.06^{c}	88.81 ± 3.27^{a}
Unica	Glucose (mg/100g)	10.56 ± 0.22^{c}	11.90 ± 0.06^{b}	9.10 ± 0.08^{d}	7.58 ± 0.04^{e}	16.47 ± 0.11^{a}
	Fructose (mg/100g)	25.34 ± 0.31^{b}	17.31 ± 0.48^{c}	15.35 ± 1.03^{d}	15.01 ± 0.25^{d}	35.35 ± 0.22^{a}
	Sucrose (mg/100g)	30.06 ± 2.09^{c}	34.65 ± 1.57^{b}	20.01 ± 0.16^{d}	18.34 ± 2.12^{e}	93.62 ± 0.35^{a}
Dutch Robjin	Glucose (mg/100g)	15.08 ± 1.01^{b}	15.11 ± 0.15^{b}	11.38 ± 0.31^{c}	8.23 ± 0.12^{d}	23.34 ± 0.02^{a}
	Fructose (mg/100g)	32.19 ± 0.32^{b}	27.95 ± 0.22^{c}	21.45 ± 0.52^{e}	24.85 ± 0.41^{d}	42.53 ± 1.33^{a}
	Sucrose (mg/100g)	45.28 ± 0.49^{b}	32.38 ± 2.03^{c}	25.45 ± 0.55^{e}	26.01 ± 0.23^{d}	109.08 ± 2.34^{a}

The results are the average of three measurements ± standard error. The presence of different letters (a, b, c, d) in the same row indicates that there are significant differences between the means ($p < 0.05$, n=3). OD-Oven Drying, LTB_OD (low-temperature blanching, 60°C for 30 minutes), HTB_OD (High-temperature blanching, 95°C for 1 minute).

The highest amount of sucrose was found in freeze-dried flour, in all the varieties. High variability in glucose and fructose was observed among the different treatments. HTB_OD and Boiling_OD potato flours resulted in the lowest sugar content. During blanching and cooking at high temperatures, the soluble sugars leached into the water, reducing the sugar content (Jangchud et al., 2003; Zhang et al., 2018). This result agrees with Olatunde et al., (2016), who found that blanching results in a reduction in sugars. Mestdagh et al., (2008) indicated that a reduction in sugar content was observed when blanching temperatures were increased. Jangchud et al. (2003) and Carillo et al. (2009) reported that solids are leached into cooking water when they are blanched or steamed.

When sugars are exposed to high temperatures, such as during boiling, some sugar molecules undergo hydrolysis, breaking down into smaller molecules. Sucrose, for instance, consists of fructose and glucose molecules. During boiling, the heat causes the bonds between glucose and fructose molecules to break, splitting the sucrose molecules into individual components (Murniece et al., 2010). This results in an overall decrease in sucrose concentration. In addition to hydrolysis, some simple sugars may undergo caramelization during boiling. When sugars are exposed to high temperatures, a chemical reaction occurs that produces brown compounds with a distinctive flavor and aroma. Caramelization can further reduce the concentration of simple sugars in the food being boiled or exposed at high temperatures (Bertrand et al., 2018).

3.3.8 Minerals content

The most abundant mineral in potato flour from the three varieties was potassium (K), followed by magnesium (Mg) and phosphorus (P). Generally, freeze-dried potato flour exhibited high mineral content, followed by oven-dried flour. The Dutch Robjin variety recorded the highest concentration in minerals content while Unica recorded the lowest. Evelyne et al. (2021) examined the nutrient content of three potato tubers grown in Kenya and found that the Dutch Robjin variety recorded the highest mineral content. This difference could be attributed to varietal differences.

On the other hand, HTB_OD and Boiling_OD potato flour recorded the lowest mineral contents (**Table 3.7).** This trend was observed in all the three varieties. Mineral leaching during cooking may be responsible for the lowest mineral content recorded in HTB_OD and Boiling_OD potato flour (Burgos et al., 2007). The lowest Fe and Zn contents for all the varieties were reported in the Boiling_OD sample. In comparison with most cereals and legumes, potato flour contained lower amounts of iron and zinc (Mestdagh et al., 2008). However, potatoes offer a higher bioavailability of iron and zinc than cereals and legumes because they contain high amounts of ascorbic acid, which promotes iron absorption, and low levels of phytic acid, which inhibits iron and zinc bioavailability (Burgos et al., 2020). In addition, potato iron is liberated from its matrix during *in vitro* gastrointestinal digestion and is, therefore, readily absorbed through the intestine (Andre et al., 2015). The lowest K (223.70 mg/100g) and Mg (35.55 mg/100g) contents were respectively reported in the HTB_OD and Boiling_OD samples. Bethke & Jansky (2008) reported that when potato tubers are boiled, the potassium and magnesium can dissolve in the cooking water, resulting in a loss of these nutrients. The same trends were observed for calcium and phosphorus. Karim et al. (2007) reported that high phosphorus content is usually related to the high amylopectin content of starch. Therefore, the higher phosphorus content recorded in freeze-drying, may be associated with amylopectin contents, and this in turn may lead to faster starch digestion and starch hydrolysis.

Table 3.7: Mineral content of potato flour form three varieties processed using different methods.

Variety	Parameters	Oven Drying	LTB_OD	HTB_OD	Boiling_OD	Freeze Drying
Shangi	Fe (mg/100g)	1.62±0.03^{a}	1.57±0.11^{b}	1.35±0.04^{c}	1.35±0.06^{c}	1.73±0.06^{a}
	Zn (mg/100g)	0.75±0.01^{b}	0.72±0.01^{cd}	0.71±0.01^{d}	0.62±0.02^{c}	0.79±0.04^{a}
	Ca (mg/100g)	12.03±0.32^{b}	11.95±0.03^{b}	11.10±0.34^{c}	11.45±0.15^{bc}	13.54±0.21^{a}
	P (mg/100g)	43.78±0.13^{b}	42.21±0.04^{c}	22.16±0.01^{e}	27.53±0.10^{d}	47.15±0.53^{a}
	K (mg/100g)	232.74±1.19^{ab}	230.59±1.19^{b}	223.70±0.99^{c}	231.82±1.19^{b}	255.95±1.59^{a}
	Mg (mg/100g)	43.54±0.05^{a}	40.30±0.42^{b}	38.70±1.72^{c}	35.55±0.06^{d}	44.90±0.32^{a}
Unica	Fe (mg/100g)	2.33±0.1^{ab}	2.84±0.31^{b}	1.41±0.23^{d}	2.04±0.05^{c}	2.89±0.55^{a}
	Zn (mg/100g)	0.99±0.01^{d}	1.25±0.02^{a}	1.14±0.11^{c}	0.67±0.21^{e}	1.19±0.04^{b}
	Ca (mg/100g)	10.56±0.66^{a}	10.31±0.03^{ab}	9.01±0.45^{c}	8.56±0.73^{c}	10.63±0.24^{a}
	P (mg/100g)	45.24±1.94^{b}	42.43±0.85^{c}	28.1±0.44^{e}	31.83±0.89^{d}	49.21±0.54^{a}
	K (mg/100g)	195.28±2.55^{a}	190.62±1.86^{b}	162.31±0.23^{c}	150.12±1.11^{d}	203.58±1.69^{a}
	Mg (mg/100g)	45.28±0.43^{b}	47.02±0.55^{a}	40.00±0.63^{c}	36.99±0.23^{d}	45.69±0.44^{b}
Dutch Robjin	Fe (mg/100g)	2.74±0.31^{a}	2.06±0.02^{b}	1.41±0.15^{c}	1.37±0.43^{cd}	2.51±0.52^{b}
	Zn (mg/100g)	1.15±0.01^{a}	1.13±0.04^{a}	1.02±0.44^{b}	0.78±1.38^{d}	1.14±0.63^{a}
	Ca (mg/100g)	13.41±0.18^{b}	11.68±1.06^{c}	11.43±0.42^{c}	10.27±0.45^{d}	14.31±0.51^{a}
	P (mg/100g)	33.45±0.31^{c}	35.33±0.22^{b}	27.01±1.34^{d}	25.12±0.62^{e}	39.22±0.26^{a}
	K (mg/100g)	263.46±3.24^{b}	256.02±0.34^{c}	214.48±1.45^{e}	222.35±1.43^{d}	284.38±1.88^{a}
	Mg (mg/100g)	47.75±1.08^{b}	48.20±1.11^{a}	45.58±0.05^{c}	38.10±0.43^{d}	47.55±1.23^{b}

The results are the average of three measurements ± standard error. The presence of different letters (a, b, c, d, e) in the same row indicates that there are significant differences ($p < 0.05$, n=3). OD-Oven Drying, LTB_OD (low-temperature blanching, 60°C for 30 minutes), HTB_OD (High-temperature blanching, 95°C for 1 minute.

3.3.9 Conclusion

In this study, the Unica variety recorded the least peeling loss, while Dutch Robjin yielded the highest flour per kg of peeled potato. Freeze-drying resulted in the highest flour yield while boiling followed by oven-drying resulted in the lowest. Freeze-drying and low-temperature blanching resulted in lighter-colored flour as opposed to boiling and high-temperature blanching (95 °C). Boiling and blanching at 95 °C treatments resulted in a low angle of repose and Carr’s index, meaning that they had good flow characteristics, suitable for easier mixing, transport, and further handling. There was a significant difference in nutrient content among the varieties, and this was influenced by different processing methods. Freeze-dried potato flour was found to preserve more nutrients compared to other processing methods. These results offer a wide range of possibilities for using potato flour in food processing and human nutrition.

CHAPTER FOUR

FUNCTIONAL PROPERTIES OF POTATO FLOUR PROCESSED USING DIFFERENT METHODS

4.1 Introduction

Potato flour is prepared by cleaning, peeling, and slicing potato tubers, pre-treatments (blanching, boiling, or soaking), drying, grinding, and finally, sieving the end-product (Lingling et al., 2019a). The procedure is standard and differs in the pre-treatments and drying methods (Hidayat & Setyadjit, 2019). It has been reported that different methods of pre-treatment and drying produce potatoes with different physical, chemical, and functional properties, as reported by various studies (Bao et al., 2021). Özdemir et al., (2022) reported that freeze-drying preserved the nutritional content of potato flour while improving its solubility and emulsifying properties. According to Bao et al. (2021), a variety of drying methods, including oven, freeze, and ethanol drying, affected the characteristics of potato flour and, therefore, on the quality of freshly prepared noodles prepared with these flours. Extrusion was reported to improve the functional properties of potato flour by enhancing its water-holding capacity, gelation properties, and pasting properties (Gborie et al., 2022). Therefore, potato flour can be processed differently for various applications in the food industry.

In the food industry, flour's functional properties are useful in selecting its potential applications (Olatunde et al., 2015). The texture, digestibility, and end-use of a food product are influenced by its pasting properties (Ocheme et al., 2018). Flour's functional properties are influenced by its chemical composition, such as starch, protein, lipids, and fiber. Ocheme et al., (2018) reported that the pasting attributes decreased as carbohydrates decreased. Protein affects the pasting properties by interacting with starch molecules and modifying their gelatinization behavior (Wu et al., 2022).

This study examined the functional properties of potato flour processed in different ways. Functional properties such as swelling capacity, solubility index and pasting properties were investigated. Potato flours were prepared as described in Chapter 3. Correlation between nutritional and pasting properties of the different flour was done. Overall, this chapter provides information about the potential end-uses of various types of flour based on their functional and pasting profiles.

4.2 Materials and Methods

4.2.1 Plant Material

The Shangi variety, the most preferred in the country, was selected and used for this study (Abong et al. 2009). Shangi is also the most perishable variety (Gikundi t al. 2021). Potato tubers were obtained from farmers in Nyandarua County, Kenya.

4.2.2 Potato flour preparation

Refer to Chapter 3, section 3.2.3 for flour preparation.

4.2.3 Particle size distribution of potato flour

Particle size distribution was determined as described by Stachowiak et al. (2021). A laser diffraction particle size analyzer (SALD-2300; Shimadzu Corporation, Kyoto, Japan) equipped with a cyclone injection unit (SALD-2300 Cyclone Injection Type Dry Measurement Unit SALD-DS5) was used. The device is capable of measuring particle size in the range of 17 nm to 2500 µm. A small amount of flour was placed into a hopper and sucked across the laser beam by pressing an ejector. The particle size distribution was determined by the light intensity distribution pattern of scattered light generated by a sample irradiated with a laser. The experiment was carried in replicate. The results were analyzed using Wing SALD II software (version 3.1.0, Shimadzu, Kyoto, Japan).

4.2.4 Microstructural Properties

4.2.4.1 Light Microscopy images of potato flour

The potato flour was observed using a polarized optical microscope (B-1000 series, OPTIKA Microscope 24010, Ponteranica (BG), Italy) equipped with a camera (Optikam HDMI Pro Camera). A thin layer of potato flour was placed on a microscope slide and dispersed using a drop of distilled water. All images were observed and photographed at × 20 magnifications under an X-LED white illumination following the methods of Kim and Kim (2015).

4.2.4.2 Scanning electron microscopy images of potato flour

Flour micrographs were taken using a Scanning Electron Microscope (model JCM-7000 NeoScope Benchtop SEM (JEOL Ltd, Tokyo Japan)). Potato flour was suspended on an aluminium stub using double-sided adhesive tape. An accelerating potential of 15 kV and a magnification of × 300 were use following a slightly modified method used by Gull et al. (2015).

4.2.5 Functional properties of potato flour

4.2.5.1 Swelling Power and Solubility Index

Swelling power and solubility were determined following the method of Yang (2020), with slight modification. 1 gram (1g) of potato flour was placed in 10 ml of distilled water and heated for 50, 60, 70, 80, and 90 °C for 30 min in a shaking water bath, then centrifuged at 1600 rpm for 15 min. The supernatant was carefully removed, and the swollen flour sediment (wet precipitate) was weighed. The aliquot of the supernatant was evaporated at 100 °C for 1 h and weighed. The difference in weight of the evaporating dish was used to calculate flour solubility. Swelling power was obtained by weighing the residue after centrifugation and dividing it by the original weight of flour on a dry weight basis (Osundahunsi et al., 2003). The procedure was repeated three times. The data for swelling power and solubility index was calculated according to the following formulas.

$$\text{Swelling power} = \frac{\text{Weight of the wet precipitate (g)}}{\text{Weight of the dried potato flour (g)}} \qquad \textbf{(Eq. 4.1)}$$

$$\text{Solubility (\%)} = \frac{\text{Supernantant concentration (mg)}}{\text{initial solution concetrantion (mg)}} \times 100. \qquad \textbf{(Eq. 4.2)}$$

4.2.6 Pasting properties of potato flour

4.2.6.1 Apparent viscosity

The apparent viscosity of potato flour was determined using a method described by Mohajan et al. (2018) with some minor modifications. Five grams of potato flour was placed in a beaked, dissolved in 100 ml of deionized water, and heated to boiling in a water bath. The beaker was removed and cooled to room temperature (~25°C). Each sample in the beaker was placed under the rotational viscometer (Visco QC-100). Using spindle number 4 and speeds of 6, 12, 30, and 60 rpm, the viscosity was measured and recorded in Pa.s.

4.2.6.2 Rapid Visco Analysis of potato flour

A Rapid Visco-Analyser (RVA) 4500 (Newport Scientific Pty. Ltd. Warriewood, Australia) was used to measure the pasting properties of potato flour according to the method described by Gelencsér (2009). Flour suspension was prepared by mixing 3.5 g of potato flour with 25 mL of deionized water in the RVA sample canister. Test runs were conducted following the profile for heat-treated flour, which included: mixing and warming up for 1 minute at 50°C; heating at 12°C per minute for 3.7 minutes up to 95°C; holding at 95°C for 2.5 minutes; cooling down to 50°C at 12°C per minute for 3.8 minutes and holding at 50°C for 2 minutes. The paddle rotation speed was kept at 160 rotations per minute throughout the analysis, except for the first ten seconds of rapid stirring at 960 rotations per minute to disperse the sample. The whole cycle was completed within 13 minutes. Several parameters were measured, including peak viscosity (Pv), breakdown viscosity (Bv), setback viscosity (Sv), final viscosity (Fv), peak time (minutes), and peak temperature (°C).

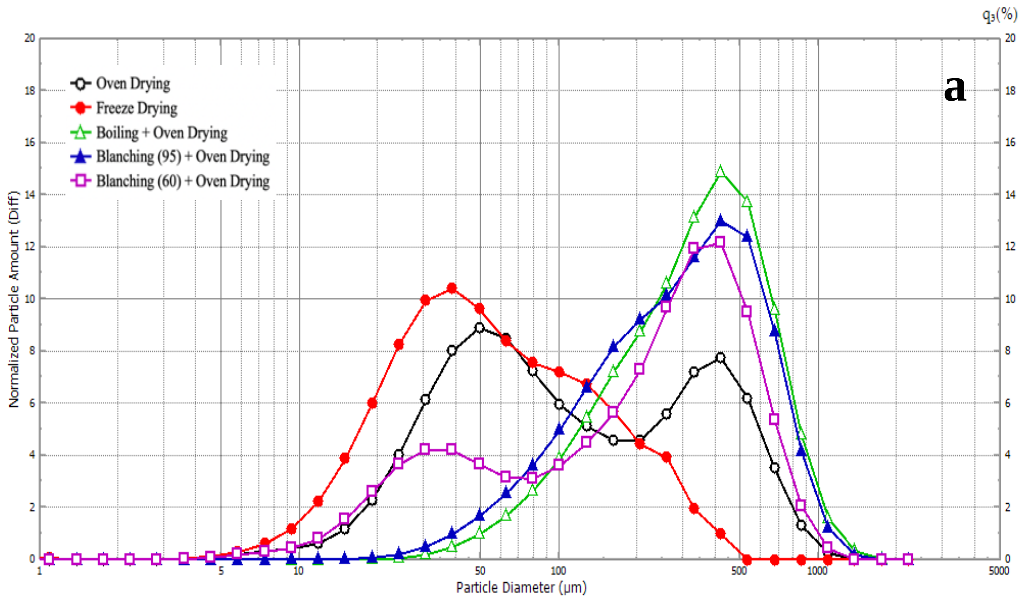
4.2.7 Statistical Analysis

Each result is an average of three determinations and is expressed as mean ± standard error. Analysis of variance and Tukey's test were performed to compare means using SPSS 18.0 (SPSS Inc., Chicago, USA) software at a significance level of 0.05%. Pearson correlation analysis was performed using the R language (version 3.2.1) at the level of $p < 0.05$, $p < 0.01$, and $p < 0.001$ for significant, quite significant, and highly significant differences, respectively.

4.3 Results and Discussion

4.3.1 Particle size distribution

The results for particle size and particle size distribution are presented in **Figure 4.1** and **Table 4.1**. The average diameter size of the potato flour ranged from 56.51 for freeze-dried potato flour to 307.53 µm for Boiling_OD potato flour. This agrees with Daudt et al. (2014), who reported that cooked flour granules have larger particle sizes, as well as larger distribution of sizes, which might be attributed to the swelling of



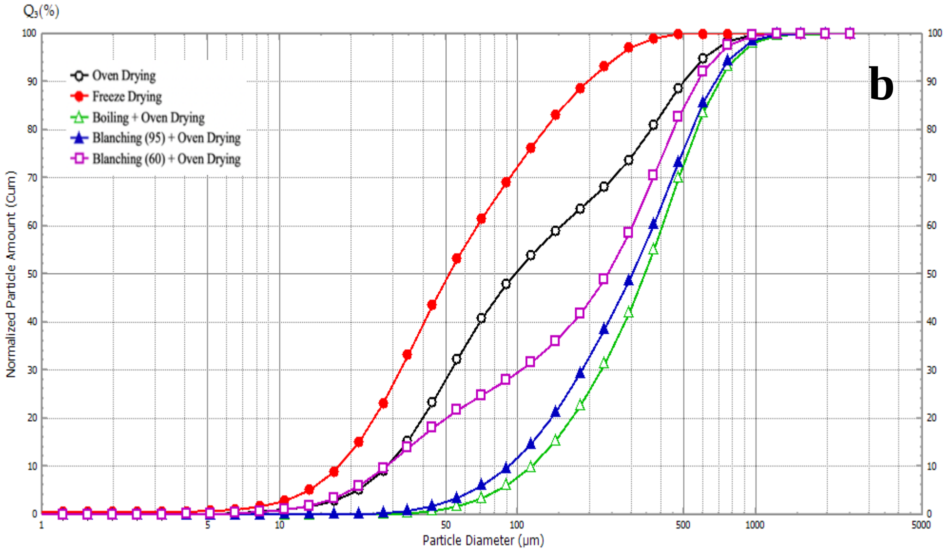


Figure 4.1: a) Particle size distribution curves and b) Cumulative undersize curves of potato flour samples prepared under different processing conditions.

A unimodal particle size distribution was observed for freeze-drying, blanching at high temperatures, and boiling, followed by oven-drying samples. The normal distribution (one peak) indicates good sample homogeneity (Cristiano et al., 2019a). On the other hand, bimodal distribution curves were observed for oven-dried flour and LTB_OD. This indicates the presence of two clusters of samples, a cluster of small samples and a cluster of large samples. **Figure 4.1b** illustrates the cumulative frequency curves for the different types of flour, starting from the smallest (freeze-dried) to the largest (boiled). This agrees with the results in **Table 4.1**. Heating at high temperatures seems to shift the size of particles from small to large. There are marked differences in the size of the particles per each percentile change in the cumulative frequency curve **(Table 4.1)** as indicated for D_{10} to D_{90}. This might point to stark differences in the morphological and functional properties of the flours.

Table 4.1: Particle size parameters of potato flour samples

Samples	D_{10} **(μm)**	D_{50} **(μm)**	D_{90} **(μm)**	***Mean*** **(μm)**
Oven-Drying (OD)	28.36 ± 0.33^{c}	97.01 ± 0.09^{d}	494.08 ± 1.36^{d}	102.74 ± 4.23^{d}
Blanching (60°) _OD	$27.050.41^{c}$	233.49 ± 3.58^{c}	562.93 ± 3.25^{c}	153.31 ± 3.18^{c}
Blanching (95°) _OD	95.55 ± 0.41^{b}	310.41 ± 5.79^{b}	668.76 ± 6.80^{b}	261.87 ± 4.17^{b}
Boiling_OD	105.14 ± 4.48^{a}	344.09 ± 3.05^{a}	708.07 ± 3.28^{a}	307.53 ± 3.71^{a}
Freeze-Drying (FD)	17.59 ± 0.13^{d}	52.87 ± 0.90^{e}	182.77 ± 6.54^{e}	56.51 ± 1.80^{e}

Results are the means of triplicate determinations ± standard error. Mean values with different letters (a, b, c, d, e) in the same column indicate significant differences based on the TUKEY test of significance ($p < 0.05$, n=3). OD-Oven Drying. $D_{10:}$ 10 % of granule volume diameter consists of smaller granules, D_{50} granule: 50 % of granule volume diameter consists of smaller granules, D_{90}: 90 % of granule volume diameter consists of smaller granules.

4.3.2 Light Microscopy (LM) and Scanning Electron Microscope (SEM)

The LM and SEM images of the potato flours prepared under different pre-treatments and drying methods are shown in **Figure 4.2**. As seen in the light microscope images and SEM micrographs, the starch granules were found to be oval-shaped for oven-dried flour, LTB_OD, and freeze-dried flour. This is in line with previous research reported by Joyner & Meldrum, (2016), who mentioned that freeze-dried granules contained no large holes, and they have typical shapes of native potato starch. Boiling and blanching at high temperatures resulted in larger and agglomerated starch granules. These findings agree with De Oliveira Do Nascimento et al. (2015), who reported that starch gelatinization and the exposure of heat to the internal starch surface causes a disruption of starch which results in swelling and eventually irregular-shaped particles. These results confirm the observed differences in particle size and particle size distribution.

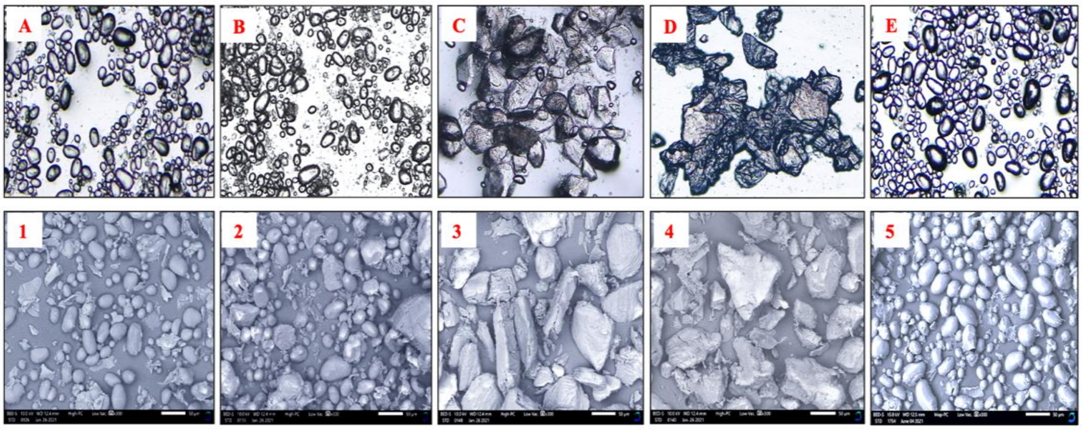


Figure 4.2: Light microscopy (A to E) and Scanning electron micrographs (1 to 5) of potato flour prepared under different conditions (A&1: Oven Drying; B&2: Blanching at low temperature (60°C); C&3: Blanching at high temperature (95°); D&4: Boiling; E&5: Freeze drying).

4.3.3 Functional Properties of potato flour

4.3.3.1 Swelling power and solubility index

The swelling power and solubility of potato flour as affected by different treatments are shown respectively in **Figures 4.3** Swelling power and solubility provide information on the nature of the associative bonding within starch granules (Fuentes-Zaragoza et al., 2010). Flour that is suitable for good functional quality has high swelling power and low solubility (Godswill et al., 2019).

The swelling power of potato flour significantly increased as the temperature increased from 50 to 90°C. This trend agrees with the results of Ríos-Ríos et al. (2016) and Duan et al., (2017). Boiling_OD and HTB_OD samples had higher swelling power than freeze-dried and oven-dried flour up to around 65 °C. This agrees with the results of Ashogbon and Akintayo (2012) who reported that pre-gelatinized flours, with probable weak bonding forces within the starch granule, show higher swelling power at low temperatures up to 70 °C but lower or remain constant beyond 70°C. Gani et al. (2010) reported that at temperatures below 60-65 °C, starch granules resist swelling probably due to their high initial gelatinization temperature. From 65 degrees and beyond, the granules gradually swelled as a result of intermolecular hydrogen bridge rupture in the amorphous areas, which allows irreversible and progressive water absorption. This was observed for freeze-dried and oven-dried flour. The resistance to swelling in freeze-dried and oven-dried flours before the onset gelatinization temperature implied the strong molecular associations, which may come from its crystalline structure and component interactions such as protein-starch complex, lipid-starch complex, and non-starch carbohydrates (Suriya et al., 2016).

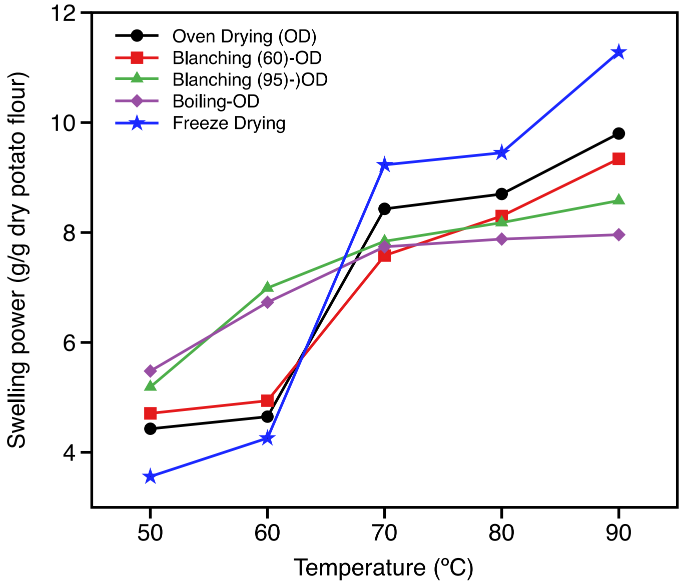


Figure 4.3: Swelling power of different potato flours at different temperatures

The high swelling power of freeze-dried and oven-dried flours just after the temperature reached the onset gelatinization point, could be attributed to their higher carbohydrates, fat, and crude fiber content which can absorb water molecules and swell (Ikegwu et al., 2009). The higher swelling power obtained in this study indicates high amylose content likely to be present in the starch granules of freeze-dried and oven-dried flour (Chisenga et al., 2019).

The solubility of flour has been reported to be mainly due to the solubility of the starch granules, which in turn depends on the amylose content (Singh et al., 2003). Sanni et al. (2001) reported that high solubility is associated with high amylose content which leaches easily during the swelling process. The results demonstrated that the solubility greatly increased as temperature increased ($R^2 > 0.98$). This agrees with Kim & Kim, (2015), who reported an increase in the solubility of potato flour with increasing temperature. The high solubility values of potato flour reported in this study would be due to the high soluble content and leaching of amylose from starch (Yadav et al., 2006). Song et al., (2017) reported that if flour or starch shows high solubility, means it contains large amounts of soluble materials. The difference in morphology can also be responsible for the differences in the solubility of starch (**Figure 4.2**). The results showed high solubility in the flour with more damaged starch such as Boiling_OD and HTB_OD flour. Fasasi et al., (2007) mentioned that more starch degradation is expected during the heating process such as boiling and blanching, thus high solubility of boiled and blanched at high temperature (95 ºC) flours. Dossou, (2014) emphasized that high solubility could be attributed to the weak forces of attraction between the molecules of flour leading to increased dissolution of the flour in water. Gujral et al. (2013) also mentioned that the degradation of amylopectin during heat treatment could cause disruption of granular structure and an increase in leaching with the heating of starch in water resulting in higher solubility. High temperatures weaken the forces of attraction between flour particles, increasing the dissolution rate in water (Dossou, 2014).

A strong positive correlation was also observed between particle size and the solubility index of potato flour (**Figure 4.4, left**). It was found that with the increasing particle size of potato flour, solubility increased. This varied a lot depending on the temperature in which the solubility of the particles was measured. The highest solubility was seen for the larger particle for a given temperature. Heat treatment disrupts the granule's structure and speeds up the leaching process of starch in water, increasing the solubility index (Gujral et al., 2013). Bala et al. (2020) reported an increase in solubility with increasing particle size for grass pea flour.

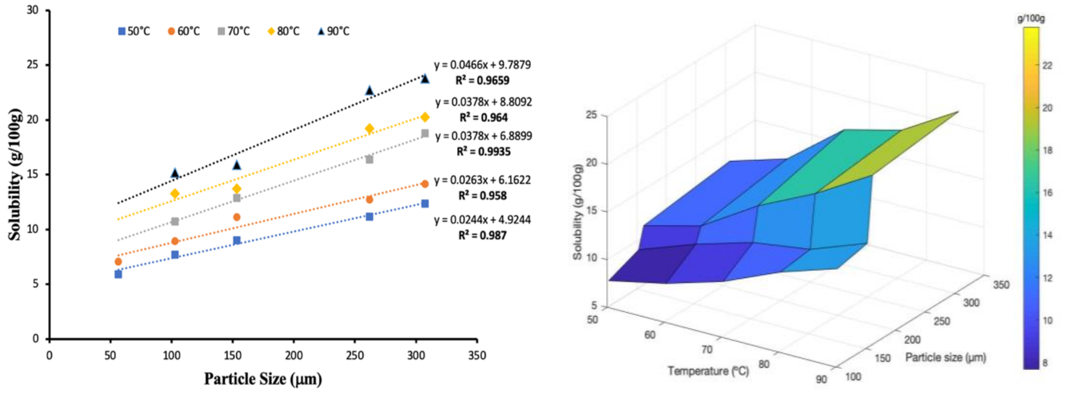


Figure 4.4: Correlation between particle size and solubility index

The relationship between particle size, temperature, and solubility is presented in **Figure 4.4 (right)**. Larger particles result in higher solubility, as indicated by the solubility contours. This was observed for Boiling_OD and HTB_OD potato flour.

Further on, solubility increased with increasing temperature for all the cases (**Figure 4.5**). The solubility curves demonstrate high correlation between temperature and solubility in all cases (R^2 =0.98), indicating the significant role of temperature in influencing solubility. The highest solubility was witnessed in boiled samples while oven drying had the lowest. Blanched samples were on intermediate solubility.

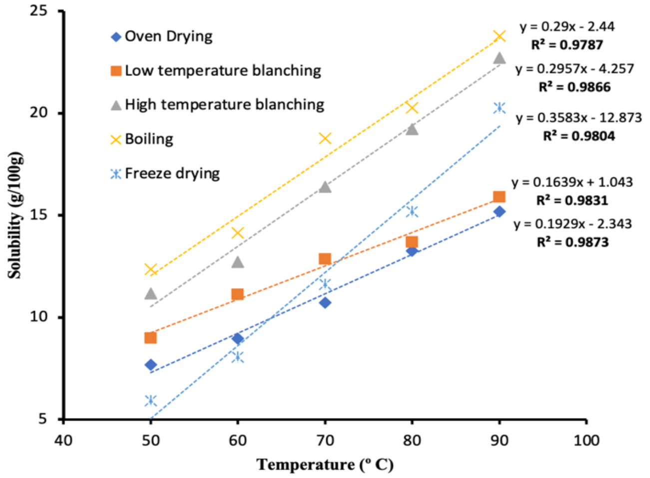


Figure 4.5: Solubility of different potato flours at different temperatures

The results of the swelling and solubility pattern of different potato flours appear to be the basis for differences in their functional properties, thus making them usable for the preparation of various end products (Yadav et al., 2006). Flours with high swelling power are associated with high pasting viscosity which is recommended as functional ingredients in the production of viscous foods (Fennema & Tannenbaum, 1996). Food products such as noodles require restricted swelling of the flour which is associated with low viscosity. Low viscosity facilitates the separation of noodles into strands during the drying process. Flour with high swelling power makes noodles soft and less firm (Galvez et al., 1994). High-quality noodles should also have low cooking losses which are associated with the low solubility of the flour (Brennan et al., 2004).

4.3.4 Pasting properties of potato flour

4.3.4.1 Apparent viscosity

The apparent viscosity of the five flour types evaluated in this study is shown in **Figure 4.6**. Viscosity refers to the resistance to the flow of a slurry system due to internal friction. As the shear rate increased, the viscosity of all potato flour types decreased, implying that the aqueous slurry behaved as a pseudoplastic fluid. Potato flour is mainly composed of starch, which accounts for its viscosity. Yang et al., (2022) reported that increasing the shear rate will result in a decrease in viscosity because of an increase in external force and the destruction of the hydration structure between polysaccharides and water molecules.

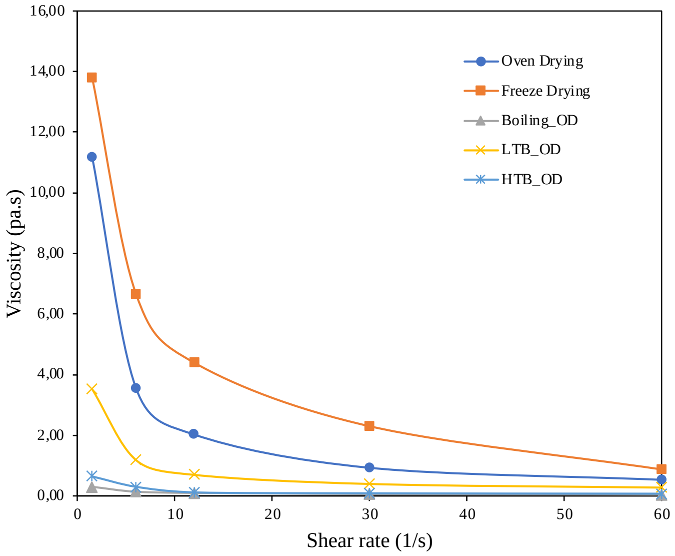


Figure 4.6: Apparent viscosity of potato flour processed using different processing methods. (HTB: High temperature blanching; LTB: Low temperature blanching)

The potato flours exhibiting the highest viscosity values were identified in freeze-dried and oven-dried samples, whereas the lowest viscosity was observed in Boiling_OD and HTB_OD potato flours. The discerned disparities in apparent viscosity can be ascribed to variations in the chemical composition of the flours, specifically regarding starch and protein content (Amini Khoozani et al., 2020). The functional properties of the flours are affected by processes such as protein denaturation and starch gelatinization during their production. Due to starch gelatinization during blanching and protein denaturation during cooking, HTB_OD and Boiling_OD potato flours exhibit lower apparent viscosities (Amini Khoozani et al., 2020). Therefore, it is suggested that freeze-dried potato flour may be used as a food thickener because of its higher viscosity (Ríos-Ríos et al., 2016) while boiled and high temperature blanched samples can be used in soups because of their low viscosity.

4.3.4.2 Pasting characteristics

The effects of different processing methods on potato flour's pasting properties are shown in **Table 4.2** and **Figure 4.7**. The peak viscosity (Pv) of the different flours ranged from 1921.33 cP to 7098.33 cP. Peak viscosity indicates the swelling of starch granules before they physically dissolve (Aidoo et al., 2022). The highest peak viscosity value was recorded for freeze-dried potato flour (7098.33 cP), while Boiling_OD potato flour recorded the lowest (1921.33 cP). This result agrees with the findings on the apparent viscosity **(Figure 4.6)**, where freeze-dried flour had the highest apparent viscosity. Flour with a high peak viscosity has a high thickening capacity (Avula & Singh, 2009). It is, therefore, possible to use freeze-dried flour to thicken food products while on the other hand, the low peak viscosity flours could be utilized in preparing weaning and supplementary foods as mentioned earlier.

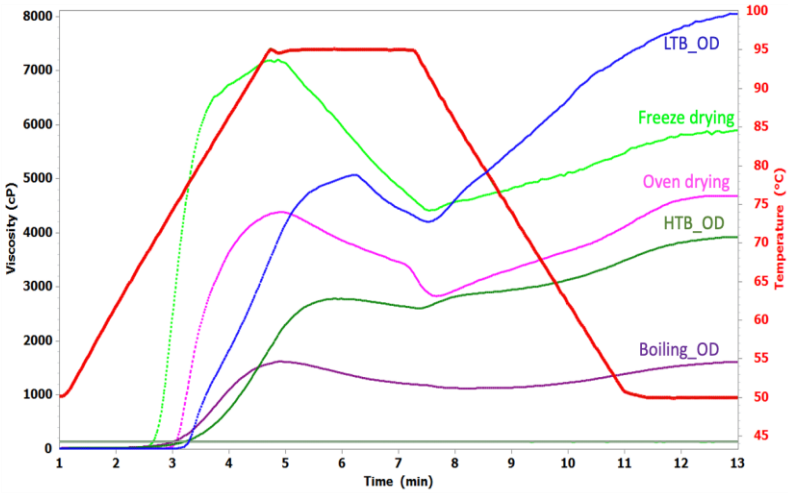


Figure 4.7: Pasting profile of potato flour processed using different methods.

Trough viscosity is a measure of the starch granules' resistance to breakdown after prolonged exposure to high temperatures (Kaur et al., 2007). Additionally, it indicates how stable is the hot paste. The lower the value, the higher the stability. Boiling_OD showed the lowest trough viscosity (1095 cP), indicating the stability of the hot paste viscosity during cooking.

Breakdown viscosity (Bv) is calculated by subtracting peak and trough viscosities after a heating ramp. Based on the breakdown viscosity, an estimation can be done on how well the paste resists disintegration when heated and sheared (Kaur et al., 2007). Freeze-dried flour recorded the highest breakdown viscosity compared to the other flour types. When the breakdown viscosity of the starch granules is high, this means that the cross-linking is weak within the starch granules. The use of such flours will result in starch breakdown at very high temperatures, so they cannot be used for products that require starch stability at very high temperatures. In contrast, potato flour with a lower breakdown viscosity may tolerate high heat treatment and shear stress, making it more suitable for use in products that need to be treated at high temperatures (Aidoo et al., 2022).

Table 4.2: Pasting properties of potato flour processed using different methods.

Pasting characteristics	**Oven Drying**	**LTB_OD**	**HTB_OD**	**Boiling_OD**	**Freeze-Drying**
Peak viscosity (cP)	4973.33±68.01^{b}	5017.67±57.92^{b}	2998.33±16.83^{c}	1921.33±13.30^{d}	7098.33±68.86^{a}
Trough viscosity (cP)	2693.33±90.40^{b}	4208.33±40.45^{a}	2638.00±30.05^{b}	1095.00±18.93^{c}	4426.33±6.06^{a}
Breakdown viscosity (cP)	1680.00±74.20^{b}	809.33±30.02^{c}	360.33±11.62^{e}	525.33±4.16^{d}	2672.00±33.69^{a}
Final viscosity (cP)	4720.33±97.45^{c}	7989.00±46.70^{a}	4027.67±50.39^{d}	1596.33±11.32^{e}	5872.00±8.19^{b}
Setback viscosity (cP)	2027.00±95.44^{b}	3780.67±28.76^{a}	1389.67±40.80^{d}	501.33±8.35^{e}	1512.33±62.52^{c}
Peak Time (Min)	4.82±0.08^{b}	6.13±0.10^{a}	5.93±0.04^{a}	4.93±0.01^{b}	4.78±0.06^{b}
Pasting temperature (ºC)	74.25±0.03^{c}	76.98±0.33^{a}	75.78±0.48^{b}	73.70±0.25^{d}	68.78±0.31^{e}

The results are the average of three measurements ± standard error. The presence of different letters (a,b,c,d,e) in the same row indicates that there are significant differences ($p < 0.05$, n=3). OD-Oven Drying, LTB_OD (Low-Temperature Blanching, 60°C for 30 minutes), HTB_OD (High-Temperature Blanching, 95°C for 1 minute). cP: Centipoise

Final viscosity is an indication of the ability of starch to form a viscous paste after it is cooked and cooled (Ashogbon & Akintayo, 2012b). Reassociation of starch molecules, especially amylose, occurs during cooling, resulting in a gel structure, which increases viscosity. Among the flours, LTB_OD had the highest final viscosity (7989 cP), while Boiling_OD had the lowest value. High final viscosities have been attributed to amylose aggregation, while low final viscosities indicate a paste's ability to resist shear stress during stirring, as reported by Liu et al. (2021). Therefore, pastes with lower final viscosity values are more stable after cooling than those with higher final viscosity.

The setback viscosity (Sv) measures the retrogradation tendency of cooked flour paste upon cooling. It has been reported that flours with high setback viscosity will have a greater tendency to retrograde (Balet et al., 2019a). Due to its low setback value, Boiling_OD potato flour demonstrated higher resistance to retrogradation. It is, therefore, possible to prepare low-viscous foods using Boiling_OD potato flour, such as complementary foods for babies. Conversely, LTB_OD, due to its high setback viscosity value, could be utilized in products requiring cold-temperature storage, such as noodles and some food products with a high viscosity.

4.3.4.3 Pearson correlation between chemical composition and pasting properties.

Correlation analysis provided insights into the relationships between potato flour's chemical composition and pasting properties (**Table 4.3**). It should be noted that results on chemical composition discussed in this section can be found in Chapter 3.

Except for pasting time and pasting temperature, all pasting properties were positively correlated ($p < 0.01$) ($r = 0.66$ to 0.91) with the moisture content of potato flour, which indicates flour with high moisture content will require a longer pasting time and lower temperatures. Furthermore, the protein content was positively correlated with trough viscosity ($r = 0.80$, $p < 0.001$), final viscosity ($r = 0.76$, $p < 0.01$), and setback viscosity ($r = 0.56$, $p < 0.05$) of the flours. Conversely, protein content was negatively correlated with peak viscosity ($r = -0.92$, $p<0.001$) and breakdown viscosity ($p = -0.84$, $p<0.001$). Proteins are negatively correlated with peak and breakdown viscosities, as reported by Yuan et al. (2021). In addition, Yuan et al. (2021) reported that proteins could reduce peak viscosity by interfering with starch granule swelling.

A negative but significant correlation was observed between fiber and peak viscosity ($r = -0.81$, $p < 0.001$). High fiber content decreases the peak viscosity of the flour. Processing HTB_OD and Boiling_OD flours caused gelatinization and retrogradation of starch, resulting in high fiber content. The high fiber content restricts the swelling of granules (Alviola & Monterde, 2018). The fat content showed a negative correlation with peak viscosity ($r = -0.83$, $p < 0.001$), trough viscosity ($r = -0.76$, $p < 0.001$), breakdown viscosity ($r = -0.78$, $p < 0.001$), final viscosity ($r = -0.73$, $p < 0.01$), and setback viscosity ($r = -0.58$, $p < 0.05$). This implies that a high-fat content decreases the viscosity of the flour. It is possible that lipids can inhibit the association between water and amylose, resulting in a slower retrogradation. Additionally, when amylose is heated and cooled, lipids form inclusion complexes that inhibit the cross-linking of starch with starch and form the solid component of the system. Amylopectin recrystallization can be inhibited by amylose-lipid complexes. Finally, lipid binding can also stabilize amylopectin, which delays retrogradation (Wang et al., 2018).

There was a significant positive correlation between the pasting properties (peak, trough, breakdown, and final viscosities) and all sugars, suggesting the amount of sugars in the flour (glucose, fructose, and sucrose) also contributes to the viscosity of the flour. It is known that sugar can increase the viscosity of flour paste because it attracts water and slows down the hydration of the starch molecules in flour. It has been reported that glucose and fructose tend to be more hygroscopic than sucrose, meaning they attract more water and can create a more liquid paste (Wang & Hartel, 2021). Sun et al. (2014) reported that glucose could enhance the onset of starch gelatinization leading to a faster increase in viscosity and higher peak viscosity. Conversely, negative correlations were observed between pasting temperature and sugars; glucose ($r = -0.64$, $p < 0.05$), fructose ($r = -0.56$, $p < 0.05$), sucrose ($r = -0.83$, $p < 0.001$). In addition, it has been reported high sugar content can lower the pasting temperature, which means that the starch granules will begin to gelatinize at a lower temperature (Spies & Hoseney, 1982). Food manufacturers and bakers need to understand the relationship between sugars and flour pasting properties to create products with desired texture, viscosity, and consistency.

Calcium content in potato flour is strongly correlated with peak viscosity ($r = 0.81$, $p < 0.001$), trough viscosity ($r = 0.66$, $p < 0.01$), and breakdown viscosity ($r = 0.87$, $p <0.001$). Calcium ions can cross-link the flour's starch molecules, forming a stronger and more stable gel network. This can lead to a higher peak viscosity, breakdown viscosity, and final viscosity (Yan et al., 2022). Magnesium ions, on the other hand, can weaken the gel network by competing with calcium binding sites on the starch molecules (Jeong et al., 2020). Consequently, peak viscosity may be lower, and setback viscosity may be higher.

Table 4.3: The correlations between the chemical composition and pasting properties of potato flour.

Chemical property	Peak Viscosity (cP)	Trough Viscosity (cP)	Breakdown Viscosity (cP)	Final Viscosity (cP)	Setback Viscosity (cP)	Pasting Temperature (°C)
Moisture	0.91***	0.91***	0.66**	0.89**	0.71**	-0.18
Protein	-0.92***	0.80***	-0.84***	0.74**	0.56*	-0.40
Ash	0.43	0.25	0.52*	0.36	0.42	-0.12
Fibre	-0.81***	-0.71**	-0.65**	-0.71**	-0.58*	0.19
Fat	-0.83***	-0.76***	-0.78***	-0.73**	-0.58*	-0.34
Carbohydrate	0.91***	-0.82	-0.80***	-0.79***	-0.62*	0.33
Glucose	0.95***	0.82***	0.93***	0.62*	0.30	-0.67*
Fructose	0.93***	0.73**	0.92***	0.58*	0.33	-0.56*
Sucrose	0.87***	0.71**	0.95***	0.43	0.07	-0.83***
Iron (Fe)	0.70**	0.37	0.88***	0.14	-0.14	-0.76**
Zinc (Zn)	0.49	0.25	0.78***	-0.04	-0.33	-0.92***
Calcium (Ca)	0.81***	0.66**	0.87***	0.45	0.15	-0.77***
Phosphorus (P)	0.86***	0.70**	0.84***	0.66**	0.51	-0.42
Potassium (K)	0.48	0.27	0.75**	0.14	-0.01	-0.63*
Magnesium (Mg)	0.79***	0.48	0.97***	0.26	-0.01	-0.76***

Note: *, **, and *** are significant at $p<0.05$, $p<0.01$, and $p<0.001$), respectively.

Potassium showed a negative correlation with pasting properties ($r = -0.63$, $p < 0.05$) and a strong positive correlation with breakdown viscosity ($r = 0.75$, $p < 0.001$). In addition, Yang et al. (2021) reported that potassium ions might enhance starch granule swelling, resulting in higher peak viscosity and a lower pasting temperature.

A strong correlation was found between potato flour's phosphorus content and its pasting properties. The phosphorus content was significantly positively correlated with peak viscosity ($r = 0.86$, $p < 0.001$) and breakdown ($r = 0.84$, $p < 0.001$). The higher the amount of phosphorus in the flour, the higher its peak viscosity. Starch hydroxyl groups are covalently bonded to phosphorus through electrostatic interactions, which lengthens the chain of short-chain starch molecules and facilitates cross-linking between them, thus resulting in high viscosity (Chen et al., 2019). Noda et al. 2004) reported a significant correlation between phosphorus content and pasting properties.

4.4 Conclusion

Freeze-drying treatment recorded the smallest particle size (56.5 µm), while boiling followed by oven drying had the largest particle size (307.5 µm). Microstructural results indicate that boiling and blanching at 95 °C, followed by oven drying resulted in damaged starch granules, while freeze-drying and low-temperature blanching (60 °C) maintained the native starch granule. The swelling power and solubility index of the potato flour increased with an increase in temperature. Particle size, temperature, and the solubility index of potato flour were strongly correlated. Boiling_OD and HTB_OD significantly reduced the apparent viscosity of the potato flours. Freeze-dried flour recorded the highest peak viscosity and would be suitable for thickening soups and other products that require high thickening power. In contrast, Boiling_OD and HTB_OD flours would be suitable for weaning and supplementary foods due to their low setback viscosity. On the other hand, LTB_OD exhibited a high setback value and could be utilized for noodles. Additionally, different correlations were established between potato flour's chemical composition and pasting properties. The various correlations established in this study indicated chemical properties such as protein, fat, carbohydrate, fiber, phosphorus, and sugars could be used as reliable attributes in predicting the pasting characteristics of potato flour. This information is useful in indicating the utilization of potato flour processed in different ways. This can help manufacturers and processors to decide which flour to use. By selecting suitable flour, they can achieve the desired texture, consistency, and quality for their final product.

CHAPTER FIVE

PHYSICAL AND RHEOLOGICAL PROPERTIES OF WHEAT-POTATO FLOUR BLENDS

5.1 Introduction

The addition of potato flour to other flours such as cereals, changes the quality of the composite flour (Yang, (2020). The incorporation of potato flour into wheat flour would enhance their nutritional, textural, and lower the allergenicity of wheat gluten (Pu et al., 2017b). The pasting properties of the blend can be influenced by the ratio of potato flour to wheat. Higher potato flour ratios generally lead to higher pasting viscosities (Xu et al., 2020). The addition of potato flour may also increase the water absorption capacity and decrease the stability of the gelatinized starch (Xu et al., 2022). Blending potato and wheat flour can affect the rheological behavior of doughs. Potato flour has a higher water-holding capacity and can result in softer doughs (Zeng et al., 2018).

Thus, understanding the physical, pasting characteristics and rheological properties of the composite flour has significant importance for the future food development process. In this study, the effect of the blending wheat flour with potato flour processed in different ways was studied. The effect on particle size distribution, pasting properties, and dough microstructural images were examined. This information is important in predicting the behavior of flour for product development.

5.2 Materials and Methods

5.2.1 Samples collection

Commercial all-purpose wheat flour was purchased from a local supermarket in Nairobi, Kenya. The Shangi potato variety was procured from a farmer in Nyandarua County, Kenya and used for flour preparation. Shangi was used because of its wide production in Kenya and its high perishability (Abong et al., 2009).

5.2.2 Potato flour preparation

The potato tubers were processed into flour using different pre-treatments and drying methods as described as shown in **Figure 5.1**. Only freeze drying and blanching at low temperature (60 °C) for 30 minutes followed by oven-dried at 50 °C for 48 hours (LTB_OD) conditions were used due to their ability to produce flours with high final viscosity as illustrated in Chapter 4. The preparation of the flours was as described in Chapter 3.

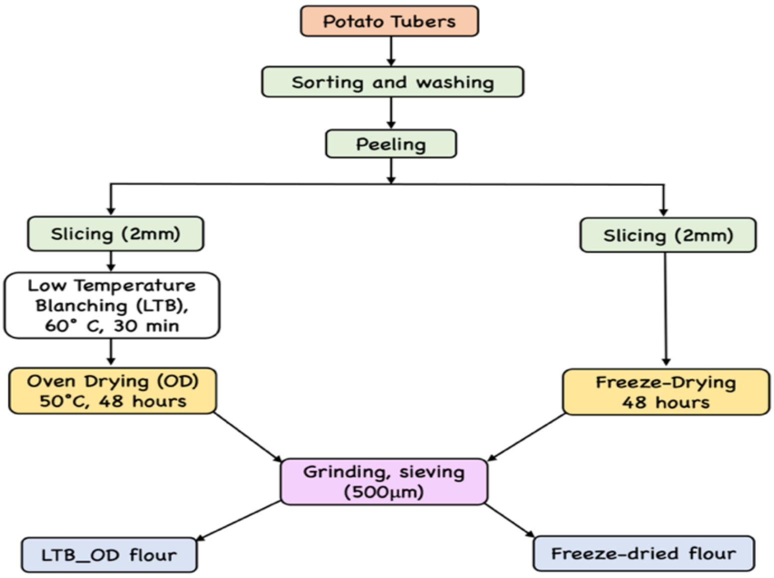


Figure 5.1: Overview chart of potato flour preparation

5.2.3 Formulation of composite flour and dough formation

Wheat flour and potato flour were mixed at different proportions, as shown in **Table 5.1**. Each of the two types of potato flour; freeze-dried and LTB_OD potato flour, substituted wheat at 10%, 30 %, and 50% ratios. The control sample was made of 100 % wheat flour.

Table 5.1: Mixing ratios (%) of wheat and potato flour blends

Sample	Mixing ratio
Wheat: Potato	10:0 (control wheat)
Wheat: 10% Potato	9:1(10% FD, 10% LTB_OD)
Wheat: 30% Potato	7:3 (30% FD, 30% LTB_OD)
Wheat: 50% Potato	5:5 (50% FD, 50% LTB_OD)

FD-freeze dried flour, LTB_OD- low temperature blanched followed by oven drying.

One kilogram of each flour blend (as shown in **Table 5.1**) was mixed with water (360 ml/kg), table salt (16 g/kg), sodium bicarbonate (2 g/kg), and sodium tripolyphosphate (2 g/kg) in a rotary mixer. A thick dough sheet was formed and allowed to rest for 20 minutes in a plastic bag.

5.2.4 Composite flour analysis

5.2.4.1 Particle size distribution

The particle size distribution of the flour was determined as described by Stachowiak et al. (2021). A laser diffraction particle size analyzer (SALD-2300; Shimadzu Corporation, Kyoto, Japan) equipped with a cyclone injection unit (SALD-2300 Cyclone Injection Type Dry Measurement Unit SALD-DS5) was used. Details on how particle size analysis was conducted can be found in Chapter 4.

5.2.4.2 Pasting properties

The pasting properties of potato flour blends were conducted using a Rapid Visco-Analyzer (RVA 4500) (Newport Scientific Pty. Ltd. Warriewood, Australia) according to the method described by Gelencsér (2009). Flour suspension was prepared by mixing 3.5 g of potato flour with 25 mL of deionized water in the RVA sample canister. Test runs were conducted following the profile for heat-treated flour, which included: 1 minute of mixing and warming up at 50°C; 3.7 minutes of heating at 12°C per minute up to 95°C; 2.5 minutes of holding at 95°C; 3.8 minutes of cooling down to 50°C at 12°C per minute and 2 minutes of holding at 50°C. A constant paddle rotational speed (160 rpm) was used throughout the analysis, except for rapid stirring at 960 rpm for the first 10 seconds to disperse the sample. The whole cycle was completed within 13 minutes. The parameters measured were: peak viscosity, highest viscosity during 95 °C heating stage; trough viscosity, lowest viscosity during 95°C heating stage; breakdown viscosity, the difference between peak and trough viscosity; final viscosity, highest viscosity during 50 °C cooling stage; setback viscosity, the difference between peak and final viscosity (Balet et al., 2019a).

5.2.5 Microstructural properties of the dough

The dough microstructure was captured using a scanning electron microscope (model JCM-7000 NeoScope Benchtop SEM (JEOL Ltd., Tokyo Japan). The inner of the dough was collected and suspended on an aluminium stub using double-sided adhesive tape. An accelerating potential of 15 kV and magnification of 270× were used during micrography following the slightly modified method used by Gull et al. (2015).

5.2.6 Statistical analysis

The data are reported as averages of triplicate observations and are expressed as mean ± standard deviation. ANOVA and Tukey’s test at a significance level of 0.05 was conducted to evaluate the significant differences among sample means. ANOVA was performed using SPSS 18.0 (SPSS Inc., Chicago, USA).

5.3 Results and Discussion

5.3.1 Particle size distribution of composite flours

Particle size is an important factor affecting the product quality and functionality of the flour (Tian et al., 2022). The particle size distribution of the various composite flours is shown in **Figure 5.2** and **Table 5.3**. The mean particle size of different flours is shown in **Figure 5.3**. Freeze-dried potato flour and wheat flour displayed unimodal distribution curves with a mean particle size diameter of 44.29 ± 0.41µm and 85.72 ± 0.70 µm, respectively **(Figure 5.2 a)**. Freeze-dried potato flour had a smaller particle size than wheat flour. The LTB_OD flour displayed a bimodal distribution with a mean particle size of 223.09 ± 0.39 µm **(Figure 5.2 b**). The larger particle size observed in LTB_OD flour compared to freeze-dried flour is attributed to the blanching (at 60 ˚C for 30 min) of potato tubers during the processing of the flour. During the heat treatment, starch granules absorb water and expand, resulting in larger particles (Kim & Qin, 2014). Ahmed et al. (2014) observed that flours with a homogeneous particle size distribution could be used to produce foods with well-defined functional properties.

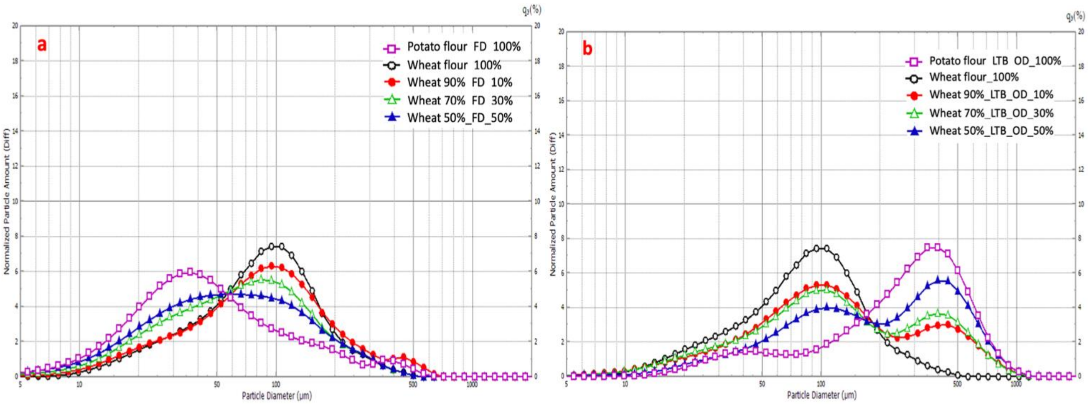


Figure 5.2: Particle size distribution curves of wheat-potato flour blends (a) freeze-dried flour (FD) (b) Low-temperature blanching followed by oven-drying flour (LTB_OD).

Substitution of wheat flour with freeze-dried potato flour significantly reduces the mean particle size, while LTB_OD flour increases the mean particle of the composite flours as seen in **Figure 5.3**. According to Hatcher et al. (2002), particle size distribution influenced the textural properties of cooked noodles. Noodles made from fine flour were significantly firmer and had higher compression resistance than those made from course flour (Hatcher et al., 2002). The particle size of flour also influences the rheology of dough (Cristiano et al., 2019). Chen et al. (2003) reported that noodles made from small-size granule fractions had better fluidity of dough for noodle making and better-quality noodles compared to large-size particles, which was attributed to larger specific surface areas of granules. Therefore, freeze-dried flours are likely to produce better quality noodles than LTB_OD flours based on their particle size.

Table 5.2: Particle size distribution of composite wheat and potato flour

Samples	*D10* (µm)	*D50* (µm)	*D90* (µm)
Wheat flour 100 %	32.84±0.69^{c}	91.34±0.50^{de}	195.68±0.69^{cd}
FD_Potato flour 100 %	14.80±0.24^{e}	41.11±0.04^{h}	162.53±1.22^{d}
Wheat 90%_FD_Potato 10 %	24.94±0.89^{d}	85.48±1.45^{ef}	226.88±1.58^{c}
Wheat 70%_FD_Potato 30 %	18.57±0.46^{e}	67.25±1.34^{fg}	187.32±5.92^{d}
Wheat 50%_FD_Potato 50 %	15.83±0.12^{e}	55.85±0.45^{gh}	193.52±17.48^{cd}
LTB_OD Potato flour 100 %	50.08±0.01^{a}	281.24±1.21^{a}	576.57±2.03^{a}
Wheat 90%_LTB_OD Potato 10 %	28.64±0.02^{cd}	107.11±1.42^{cd}	464.02±1.34^{b}
Wheat 70%_LTB_OD Potato 30 %	28.40±0.63^{cd}	115.49±1.01^{c}	495.19±9.87^{b}
Wheat 50%_LTB_OD Potato 50 %	37.96±2.61^{b}	165.89±11.93^{b}	544.18±9.11^{a}

Results are the means of triplicate determinations ± standard deviation. Mean values with different letters (a, b, c, d, e) in the same column indicate significant differences ($p < 0.05$, $n = 3$). FD- freeze-dried, LTB_OD- low-temperature blanching followed by oven drying.

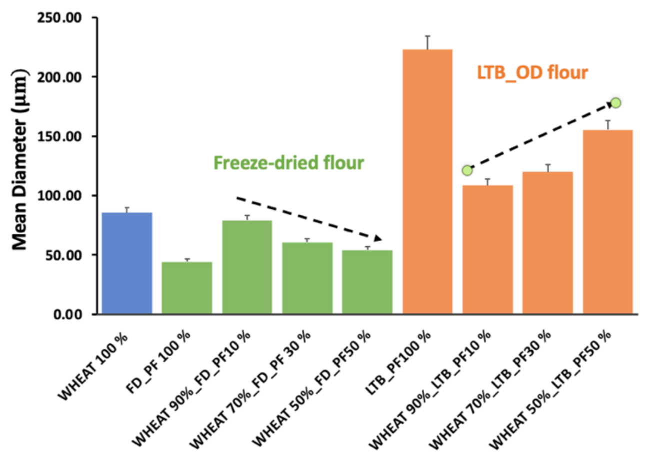


Figure 5.3: Mean diameter of different composite flours

5.3.2 Pasting properties of composite flours

The pasting properties of flour refer to the behavior of flour when heat is applied to it in the presence of water. This affects the texture, digestibility, and end-use of the flour (Ocheme et al., 2018). In this study, the pasting profiles of wheat-potato flours blends were determined to evaluate their suitability for noodles production. The results of the pasting properties of wheat-potato flour blends are shown in **Figure 5.4** and **Table 5.4**. All pasting parameters measured were significantly higher in the composite flours than in the control (100% wheat flour) except for the breakdown viscosity. The results also showed that the peak viscosity, trough viscosity, final viscosity, and setback viscosity increased with the replacement of wheat flour. The results are even more distinct for freeze dried composite flours as compared to LTB_OD composite flours. This might be attributed to the differences in morphology and chemical composition highlighted in earlier chapters. Potato starch has a higher viscosity than starches from cereals such as wheat, rice, and corn. This is attributed to the high swelling power of potato starch compared to other starch types (Waterschoot et al., 2015). The high swelling power of potato starch during heating is due to high phosphate groups bound to amylopectin. Repulsion between phosphate groups on adjacent chains increases hydration by weakening the extent of bonding within the crystalline domain (Noda et al., 2004; Karim et al., 2007).

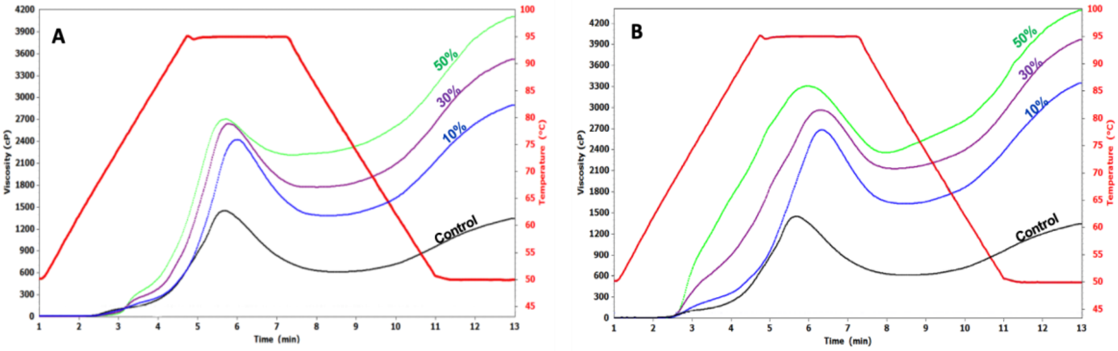


Figure 5.4: Pasting profile curves of wheat flour and the different blends. (A) Low-temperature blanching (60°C) potato flour, (B) Freeze-dried potato flour, Control- 100% Wheat.

In predicting noodle quality using pasting properties, Konik et al., (1992) showed that breakdown and final viscosity were useful indicators of noodles quality of Japanese white salted noodles. In another study, Ross et al. (1994) observed a significant correlation between all pasting properties of flour and the surface smoothness, firmness, and elasticity of alkaline noodles. And the best parameters for predicting alkaline noodles were final and breakdown viscosity.

According to Zaidul et al. (2007), highly swollen starches increase the smoothness and reduce the firmness and elasticity of noodles, thereby lowering the total textural quality. Meaning high viscosity flours are not suitable for noodle making. Therefore, the ideal starch base for preparing noodles is one with restricted swelling and viscosity that remains constant or even increases during continued heating and shearing, indicative of good hot paste stability noodles (Sandhu & Kaur, 2010).

Table 5.3: Pasting properties of wheat and potato flour blends.

Samples	**Peak viscosity (cP)**	**Trough viscosity (cP)**	**Breakdown viscosity (cP)**	**Final viscosity (cP)**	**Setback viscosity (cP)**	**Pasting Temperature (°C)**
Wheat flour (100%)	1450.7±53.99^{e}	610.0±17.04^{f}	840.67±37.35^{c}	1356.0±32.14^{f}	746.0±26.23^{e}	86.12±0.28^{a}
Wheat 90%_FD_Potato 10 %	2595.3±53.44^{c}	1562.3±44.86^{d}	1033.0±12.12^{a}	3257.0±60.66^{d}	1694.7±27.39^{c}	70.98±0.02^{c}
Wheat 70%_FD_Potato 30 %	2936.0±21.50^{b}	2096.0±48.49^{b}	840.0±29.36^{c}	3903.3±42.60^{b}	1807.3±20.95^{b}	69.86±0.23^{d}
Wheat 50%_FD_Potato 50 %	3294.3±27.70^{a}	2327.7±31.84^{a}	966.6±9.35^{ab}	4342.0±52.63^{a}	2014.3±21.06^{a}	69.32±0.04^{d}
Wheat 90%_LTB_Potato 10 %	2354.7±34.91^{d}	1342.7±24.73^{e}	1012.0±10.26^{a}	2865.0±43.06^{e}	1522.3±18.34^{d}	86.67±0.46^{a}
Wheat 70%_LTB_Potato 30 %	2626.0±21.59^{c}	1761.0±11.53^{c}	865.0±10.59^{bc}	3503.0±15.17^{c}	1742.0±4.16^{bc}	75.88±0.02^{b}
Wheat 50%_LTB_Potato 50 %	2764.3±51.16^{bc}	2153.0±70.69^{ab}	611.3±27.72^{d}	4156.3±61.93^{a}	2003.3±13.48^{a}	75.07±0.02^{b}

Results are the means of triplicate determinations ± standard deviation. Mean values with different letters (a, b, c, d, e, f) in the same column indicate significant differences ($p < 0.05$, n = 3). FD- freeze-dried, LTB_OD- low-temperature blanching followed by oven drying.

5.3.3 Microstructure images of the dough substituted with different levels of potato flour.

The scanning electron micrographs of the dough samples are shown in **Figure 5.5**. The control sample (wheat dough 100%) was characterized by the presence of small and large starch granules, which were tightly dispersed in a network structure. Similar observations of wheat dough have been previously reported (Li et al., 2020; Xu, et al., 2022). Xu et al., (2017a) reported that wheat dough forms a more continuous gluten network and exhibits a distinguishable gluten film structure entrapping the starch granules. The wheat dough sample showed a compact microstructure with fewer hollows and voids. With the addition of potato flour, the continuity of the gluten network structure becomes fragile and the ability to wrap the starch granules becomes lower. When the added amount of LTB_OD potato flour was 10%, it could be seen that starch granules start separating. The effect was more noticeable when the added amount of LTB_OD potato flour was 30% and 50%, more hollows and porous structures were visible. This can be associated with the mean particle size of LTB_OD potato flour that was way larger than that of freeze-dried potato flour. These findings agree with Xu et al. (2022) who reported that more membrane-like structures were observed in partially gelatinized potato starch granules dough than in native-gluten model dough. Jian et al. (2020) attributed this to the formation of a three-dimensional network with branches and edges from starch particles after gelatinating. The SEM results are consistent with the pasting properties discussed earlier. Cao et al., (2020) reported that the substitution of potato flour and potato pulp breaks the gluten network, therefore changing the viscoelasticity of the dough.

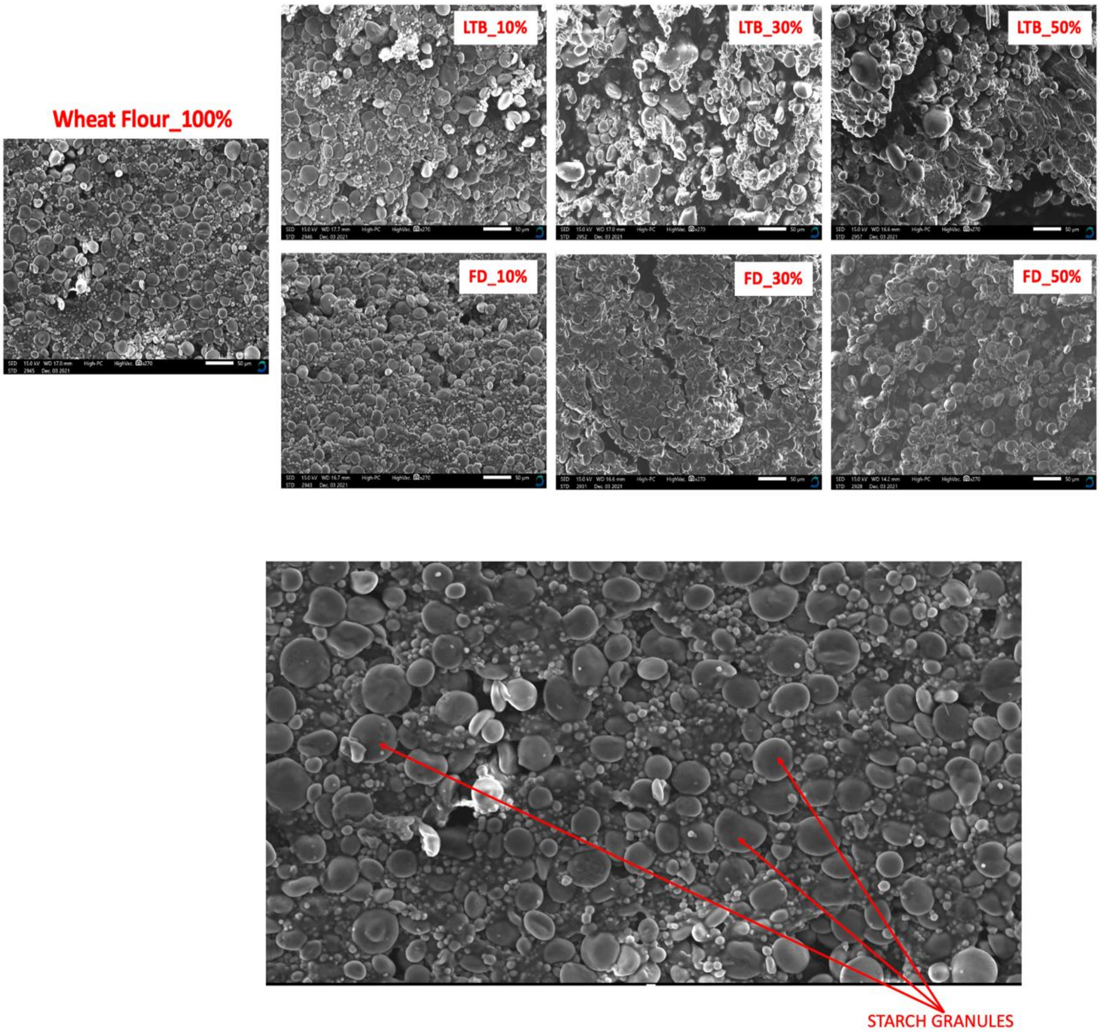


Figure 5.6: Scanning micrographs of dough substituted with different levels of potato flour (270×)

5.4 Conclusion

This study evaluated the effect of substituting wheat flour with different ratios of potato flour (10%, 30% and 50%) on some physical properties, pasting properties and dough rheology. The addition of potato flour to wheat flour significantly affected the particle size of the composite flour. LTB_OD blends resulted in bigger particle sizes. The pasting properties increased with the addition of potato flour. Freeze drying exhibited the highest values compared to LTB_OD. The SEM imagines showed a gradual disintegration of the protein-starch matrix of the dough as the amount of potato flour increased. The effect more noticeable when LTB_OD potato flour was added. The results from this chapter demonstrate that both flours have great potential for application in noodles processing and other bakery products like bread, chapatti, among others.

CHAPTER SIX

EFFECT OF POTATO-WHEAT FLOUR BLEND ON PHYSICAL AND SENSORY PROPERTIES OF NOODLES

6.1 Introduction

Potato flour is frequently used as a thickener, color or flavor improver. It is used in sauces, gravy, bakery products, extruded products, fabricated snacks, and soup mixes (Yadav et al., 2006). In wheat-based products, potato flour has been used to reduce the dependency on wheat flour and lower the allergenicity of wheat gluten (Meng et al., 2022). Noodles are wheat-based products that have been enriched with potato flour (Nawaz et al., 2019a; Pu et al., 2017a).

Noodles are convenient, easy to cook, delicious, low cost, and have a relatively long shelf-life, which suits the busy lifestyle of students and the working population (Onyema et al., 2014; Sikander et al., 2017). Traditionally, noodles are made from wheat flour, water, and salt through dough mixing, sheeting, and cutting (Fu, 2008). Gluten protein and wheat starch are essential to noodle quality. The gluten protein and wheat starch in the dough system are critical parameters to consider for good quality of noodles (Katyal et al., 2016). Nawaz et al., (2019) and Pu et al. (2017) reported that the addition of potato flour affects the starch-protein matrix, textural characteristics, cooking qualities, starch, and protein quality. Gluten acts as the skeleton, while wheat starch serves as the filler in the noodle dough. Gluten is responsible for dough elasticity and strength (Kovacs et al., 2004). Replacement of wheat flour with gluten-free potato flour is likely to affect the noodle quality due to changes in protein quality, quantity, and starch quality (starch type and gelatinization degree).

Several studies have reported changes in the physicochemical properties of potato flour produced using different methods (Bao et al., 2021). However, limited information is available on the properties of noodles made from potato flour processed in different ways. Thus, this study aims to investigate the effect of partial substitution of wheat flour with potato flour processed using different methods on the cooking, textural, and sensory properties of noodles. The flour processing methods used included freeze-drying (FD) and low-temperature blanching (60˚C) followed by oven drying (LTB_OD). The results of this study will provide a better understanding of the impact of potato flour processing on the production of potato noodles.

6.2 Materials and Methods

6.2.1 Potato flour preparation and wheat flour acquisition

The preparation of potato flour and procurement of wheat is as described in section 5.2.1 and 5.2.2.

6.2.2 Formulation of composite flour

Wheat flour and potato flour were mixed at different proportions, as shown in **Table 6.1**. Each of the two types of potato flour; freeze-dried and LTB_OD potato flour, substituted wheat at 10%, 30 %, and 50% ratios. The control sample was made of 100 % wheat flour.

Table 6.1: Mixing ratios (%) of wheat and potato flour blends

Sample	Mixing ratio
Wheat: Potato	10:0 (control wheat)
Wheat: 10% Potato	9:1(10% FD, 10% LTB_OD)
Wheat: 30% Potato	7:3 (30% FD, 30% LTB_OD)
Wheat: 50% Potato	5:5 (50% FD, 50% LTB_OD)

FD-freeze dried flour, LTB_OD- low temperature blanched followed by oven drying.

6.2.3 Noodle production

The noodles were processed using a method previously described by Tiony & Irene, (2021) with some modifications. One kilogram of each flour blend (as shown in **Table 6.1**) was mixed with water (360 ml/kg), table salt (16 g/kg), sodium bicarbonate (2 g/kg), and sodium tripolyphosphate (2 g/kg) in a rotary mixer. A thick dough sheet was formed and allowed to rest for 20 minutes in a plastic bag. The dough was then passed through extension rollers to reduce thickness. The thin sheet of dough produced was passed through a shredder. The shredded dough was then cut at 10 cm spacing, steamed for 20 min, and deep fried at 140 °C in cooking oil for 30 s. The instant-fried noodles were cooled at room temperature and packed in airtight bags.

6.2.4 Noodles color determination

Potato flour color was measured according to Pandey et al. (2022) using HunterLab's ColorFLex EZ spectrophotometer, USA. The instrument was first calibrated using white and black tiles as the standards. Noodles strands were tightly packed in an optically transparent glass cup and covered with an opaque cover, used as a light trap to prevent the external light from interfering with the sample cup. The clear glass containing the packed noodles was then placed on the port. Light from the spectrophotometer was flashed on the sample, and the color intensity was recorded. The noodle's color was reported in terms of 3-dimensional color values on the following rating scale: Lightness L* ranges from (black (0) to light (100)), a* from red (60) to green (−60), and b* ranges from yellow (60) to blue (−60). All the results were an average of the triplicate readings.

6.2.5 Cooking properties

6.2.5.1 Water absorption capacity (WA)

The weight of cooked noodles was evaluated using a method described by Yadav et al., (2014) with minor modifications. Three grams (3 g) of noodles were boiled in 200 ml of water until cooked (when the center of the noodles became transparent. It took around 4 minutes). The cooked noodles were rinsed with distilled water, drained for 5 min, and weighed immediately. The following equation was used to calculate the weight of cooked noodles:

$$\textbf{Cooked noodles weight} = \frac{(\mathrm{WA1} - \mathrm{WA2})}{\mathrm{WA2}} \times 100 \qquad \textbf{(Eq. 6.1)}$$

Where, WA_1: Weight of cooked noodles; WA_2: Weight of the uncooked noodles

6.2.5.2 Cooking loss

The cooking loss was determined according to the method described by Yang et al. (2022). Ten grams (10 g) of noodles were boiled in 500 mL of deionized water until cooked. The remaining cooking water was collected into a 500 mL volumetric flask and topped to volume with distilled water. Afterwards, 50 mL was placed into a 250 mL beaker (pre-dried to constant weight). Then, the beaker was placed in an oven drier at 105 °C until a constant weight was achieved. The following equation was used to calculate the cooking loss:

$$\textbf{Cooking loss} = 10 \times \frac{(W4-W3)}{W2} \times 100 \qquad \textbf{(Eq. 6.2)}$$

Where W_2 is the mass of the noodles before cooking (g), W_3 is the mass of the beaker before drying (g), and W_4 is the mass of the beaker after oven drying with dried substances of the cooking water (g).

6.2.6 Textural properties of cooked noodles

The textural profile of noodles was evaluated using a texture analyzer (CT3, Brookfield, USA) equipped with a 1,500 g load cell and TexturePro CT software version 1.4 (Brookfield Engineering Laboratories, Middleboro, MA, USA), according to a reported method by Thuy et al. (2020). The measurements were taken under the following settings: text type TPA (texture profile analysis); test speed: 2 mm/g; target type: Stop @ Load; target value: 1000 g and trigger force: 5 g. A wedge-shaped probe (part number TA- PFS-C) was used for texture profile analysis. The noodles were cooked in boiling deionized water (approximately 4 minutes), followed by cooling for 1 min under running distilled water and draining off the water before measurement. Five cooked noodle strands were randomly picked and placed perpendicular to the long edge of the probe on the fixture base table. From force-time curves of the TPA, hardness, resilience, springiness, cohesiveness, gumminess, and chewiness were determined. Hardness is the maximum force registered during the first compression cycle. Resilience is measured after the first penetration is withdrawn before the waiting period is started. Springiness is defined as the height that the sample recovers during the time elapsed between the end of the first bite and the start of the second. Cohesiveness is determined as the ratio between the positive area of the second cycle and the positive area of the first cycle (Funami & Nakauma, 2022).

6.2.7 Sensory evaluation of cooked noodles

Sensory evaluation of the noodles was conducted based on the method proposed by Ibitoye et al. (2013) with slight modifications. All noodles' samples were cooked and served to 40 untrained panelists. Samples were coded with random numbers and served in random order. Preference for noodle samples was characterized by a 9-point hedonic rating scale which rates 9-as "like extremely" and 1-as "dislike extremely" for appearance, texture, aroma, taste, and general acceptability.

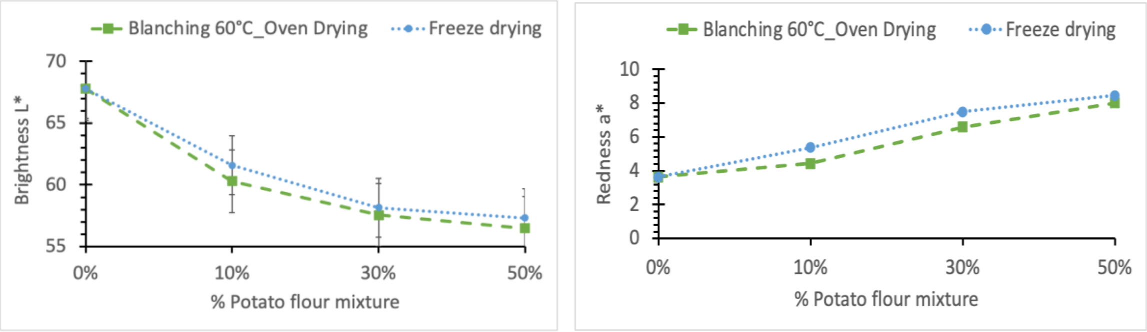
6.2.8 Statistical analysis

All experiments were performed in triplicate and expressed as mean ± standard deviation. Analysis of variance was performed using SPSS 18.0 (SPSS Inc., Chicago, USA), and Tukey's test at a significance level of 0.05 was conducted to separate the means.

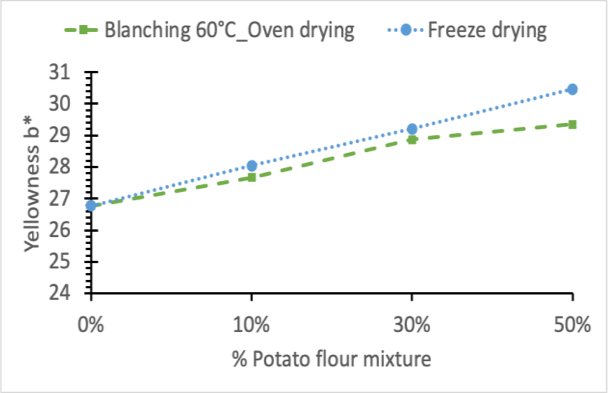
6.3 Results and Discussion

6.3.1 Color properties of noodles

The color of noodles is an important quality determinant. Consumers prefer bright and uniform-colored noodles without faded patches (Li et al., 2017). The results of color measurement are shown in **Figure 6.1** while images of noodles made from the potato-wheat blend are shown in **Figure 6.2.** The control sample had the highest lightness (67.77 ± 0.23), while wheat flour substituted with 50% LTB_OD potato flour had the lowest lightness (56.49 ± 0.01). There were significant decreases in noodle brightness (L*) with the addition of potato flour. Among the flour blends, freeze-dried flour gave brighter noodles than LTB-OD flour noodles. Yang, (2020) reported that ingredients other than wheat flour decrease the L* value of noodles. These results agree with Desai et al., (2018) and Kowalczewski et al., (2015) who reported a decrease in noodles' brightness after incorporating fish power and potato juice into wheat flour, respectively.



Brightness (L*) **Redness (a*)**



Yellowness (b*)

Figure 6.1: Color characteristic for fried noodles enriched with potato flours at 0%, 10%, 30%, and 50%

As the amount of potato flour increased, there was a significant increase in noodles' redness (a*) and yellowness (b*) values. The color of the noodles gradually became more yellow. This might be attributed to the high sugar content of potato flour. During cooking, the sugars are likely to combine with the protein to form Maillard reaction products (Marquez & Anon, 1986; Kolarič et al., 2020; Nawaz et al., 2019a).

Figure 6.2: Image of noodles with different levels of potato flour processed using different methods, LTB- low-temperature blanching followed by oven drying, FD- freeze dried.

6.3.2 Cooking Properties

6.3.2.1 Weight of cooked noodles

The results of the noodle's cooked weight are presented in **Figure 6.3**. The weight of cooked noodles increased with the replacement of wheat flour with potato flour. This might be attributed to potato starch properties during cooking (Pu et al., 2017a). Noodles with 30% freeze-dried potato flour had the highest weight (93.83% ± 0.51), while the control had the lowest weight (85.81 ± 0.54). The increase in the cooking weight of the noodles indicates that potato flour substitution increased the water-binding capacity of the noodle during cooking (Pu et al., 2017a) up to a maximum level at 30% substitution. Higher swelling and viscosity profiles of the potato starch could be attributed to the higher cooking weight of potato blend noodles (Sandhu & Kaur, 2010). However, substituting freeze-dried potato flour beyond 30% slightly reduced cooked weight from 93.83% ± 0.51 to 92.99% ± 0.37. This could be attributed to due to the weakening of the gluten network as a result of decreased gluten protein content (Majzoobi et al., 2011).

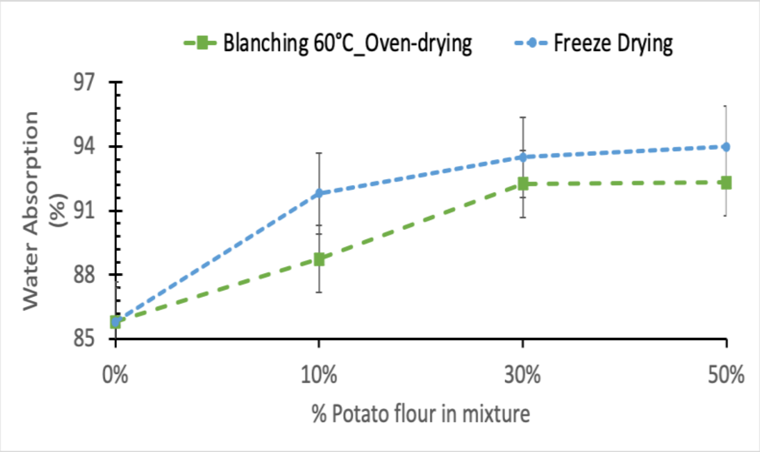


Figure 6.3: Water absorption of wheat noodles substituted with different levels of potato flour processed using different methods.

6.1.1.1 Cooking loss

The cooking loss of noodles significantly ($p < 0.05$) increased proportionally to the increase in potato flour content as shown in **Figure 6.4**. Cooking loss is related to the amount of solid substances lost in the cooking water during the boiling period (Rombouts et al., 2014). Noodles of good quality should lose little solids in the cooking water. Noodles made with 50% of LTB_OD flour had the highest (10.62% ± 0.09) cooking loss, while the control had the least (2.61 % ± 0.17). Substitution with either potato flour up to 10 % didn’t present any difference in cooking loss. However, as the concentration of potato flour increased stark differences are observed at 30% and 50% substitution, with more loss being exhibited by the LTB_OD potato flour sample. This could be due to the larger particle size of LTB_OD potato flour. High cooking loss is undesirable in noodles as it represents high solubility of starch and low cooking tolerance, resulting in a sticky texture (Sandhu & Kaur, 2010).

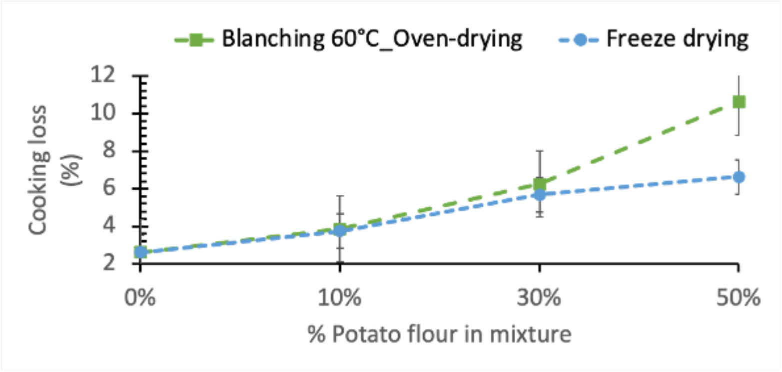


Figure 6.4: Cooking loss of wheat noodles substituted with different levels of potato flour processed using different methods.

In addition, Kawaljit & Maninder, (2010) reported that adding potato starch increased the starch, which decreased the noodle's cohesiveness. With the high starch content, the microstructure of the noodles is destroyed and becomes loose, which causes more starch to be released into the cooking liquid and increases the cooking loss.

6.3.3 Texture profile analysis

Textural properties are considered one of the most critical characteristics in evaluating the quality and determining consumer acceptability of noodle products (Jia et al., 2019). **Figure 6.5** shows the texture profile analysis (TPA) parameters of noodles made from the different wheat and potato flour blends. The hardness (A), resilience (B), cohesiveness (C), springiness (D), gumminess (E), and chewiness (E) characteristics, were performed. The value of all these parameters were less than those of control noodles which were made of 100% commercial wheat flour. These results suggest that the textural attributes of noodles were affected by the addition of potato flour.

Noodles with 10% LTB_OD potato flour had the highest hardness values but did not significantly differ from the control and 10% freeze-dried potato flour noodles (**Figure 6.5_A**). Noodles with 50% freeze-dried and LTB_OD potato flour had lower hardness and significantly differed from the other flour blends. Hardness corresponds to the stress required to deform a food to a certain deformation (Funami & Nakauma, 2022). Hardness is considered a key indicator of the overall texture quality of noodles (Zou et al., 2021). Similar results were reported by Nawaz et al. (2019a) who attributed the decrease in hardness to the weakening of the gluten network and disulphide bonding in the noodles. Deng et al (2023) reported that excessive addition of modified potato flour would reduce the gluten protein content in wheat flour, and would weaken the network of flour dough, resulting in poor texture properties of the noodles. On the other hand, an increase in hardness with the substitution of wheat flour with potato flour has been reported by Pu et al., (2017b) and Deng et al. (2023) and was attributed to the interactions between the components of potato and wheat flour and the increase in water absorption in the potato-wheat system which would make starch particles filled in the gluten network, which would reduce elasticity of the dough and hindered the formation of gluten network structure, thus resulting in the reduction of pores and the increase of the hardness of noodles.

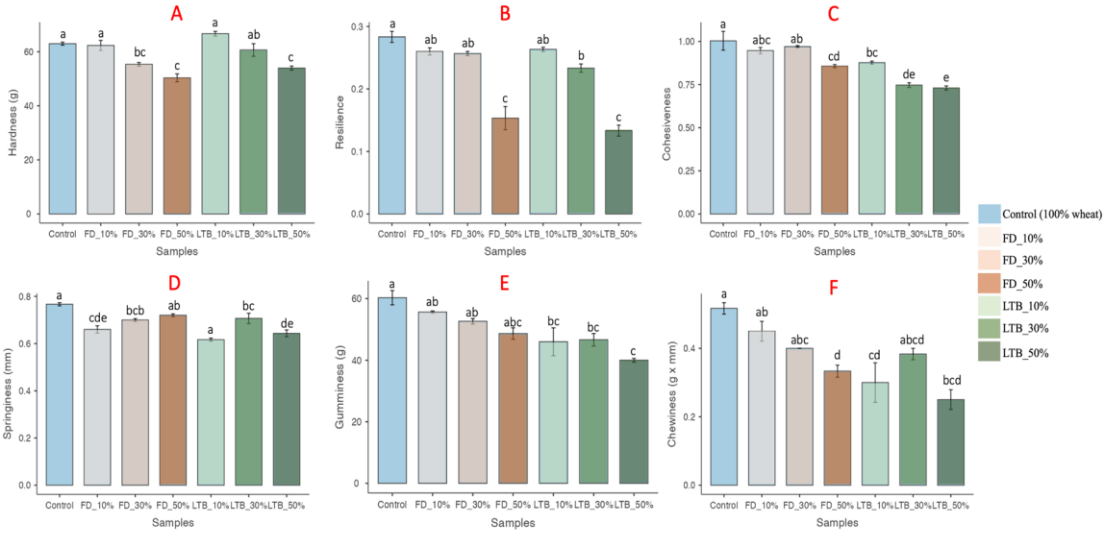


Figure 6.5: Texture profile analysis (TPA) parameters of cooked noodles with different potato flour/wheat flour ratios. (A: Hardness, B: Resilience, C: Cohesiveness, D: Springiness, E: Gumminess and E: Chewiness)

Resilience **(Figure 6.5_B)** describes the rubbery state of the noodles and is a measure of recoverable energy after compression, It provides insight into the structural matrix (Jia et al., 2019). In other terms, it explains how well a food product returns to its original shape after deformation. The resilience of noodles made with the different blends decreases with adding potato flour. However, the replacement of up to 30% of freeze-dried potato flour gave noodles resilience comparable to the control noodle. Practically, the decrease in resilience in blends noodles means that the noodles will feel less spring or elastic when you bite into them or manipulate them. They may deform more easily and not offer the same level of resistance to chewing as noodles made solely from 100% wheat flour. These effects may be perceived as positive for consumer that prefer softer noodle texture (Hatcher 2001).

Cohesiveness **(Figure 6.5_C)** is defined as the strength of the internal bonds making up the body of the product (Funami & Nakauma, 2022). It measures the extent to which the noodle structure is disrupted in the first bite. The control noodles showed the highest cohesiveness and were not significantly different from noodles made from 10% and 30% freeze-dried potato flour. Noodles made from LTB_OD flour blend had lower cohesiveness and decreased significantly compared to the control. This means that these noodles are more prone to falling apart or disintegrating during handling or chewing. They will show tendence to break apart more easily when you try to pick them up. The strength of the noodles depends on the starch-gluten network, the addition of potato flour increases the starch content and dilutes the gluten content, consequently weakening the starch-gluten network (Nawaz et al., 2019a).

Springiness measures the ability of noodles to return to their original shape after compression. Springiness **(Figure 6.5_D)** decreased with the incorporation of potato flour but no significant changes was observed among the blend noodles. These results might be related to the fact that the incorporation of potato flour reduced the gluten content in dough, leading to the deterioration of the network structure (Park and Cho, 2004)

The gumminess **(Figure 6.5_E)** refers to the degree of stickiness. The gumminess of noodles made with the different blends decreases with adding potato flour. Noodles with less gumminess may feel smoother and less sticky in the mouth. This can be perceived as easier to chew and swallow as they don’t adhere strongly to the teeth.

The chewiness **(Figure 6.5_F)** shows the energy required to turn the noodles into a swallow-able state. It is associated with difficulty in chewing the product (Joshi et al., 2018). The chewiness and gumminess values of all blend noodles were lower than the control noodles. Baik & Lee (2003) observed a linear relationship between chewiness and protein content. Gluten is responsible for dough elasticity and strength (Kovacs et al., 2004). Blending wheat flour with potato flours impairs the gluten matrix, weakening the noodle's texture. Xu et al. (2017) reported that other components in potato flour, such as fibers, protein, and gelatinized starch, could dilute the gluten content in dough samples resulting in fragile noodles during cooking. Similarly, a study on the effect of different proportions of potato flour on the noodle's quality showed that the noodles deteriorated in terms texture when potato flour was more than 40% (Nawaz et al., 2019a). Li et al. (2018) suggested that adding potato flour spoiled noodles' textural attributes and concluded that a high degree of gelatinization of potato flour could also weaken the gelling properties of noodles during cooking. Blending wheat flour with up to 30% freeze-dried flour and 10 % LTB_OD gave good textured noodles compared to the control.

6.3.4 Sensory evaluation of cooked noodles

The sensory attributes of cooked noodles produced from wheat and potato flour blends are shown in **Figure 6.6**. The sensory assessment is a subjective estimation and assesses the overall acceptability of a food product. Therefore, it plays a significant role in selecting a food item (Sharif et al., 2017). The results show that replacing wheat flour with potato flour significantly affected the overall sensory scores of noodles. Noodles substituted with freeze-dried potato flour up to 30% were the most accepted, followed by noodles substituted with 10% of LTB_OD. No significant difference ($p \leq 0.05$) was reported between the control (100% wheat) and freeze-dried potato flour at 10%. The aroma and texture of the noodles were the most affected sensory attributes when potato flour portions were increased. Substituting the noodles with 50% LTB_OD potato flour scored the lowest values in appearance and taste. Zhang et al. (2010) reported that consumers prefer clear, bright noodles free of darkening or discoloration.

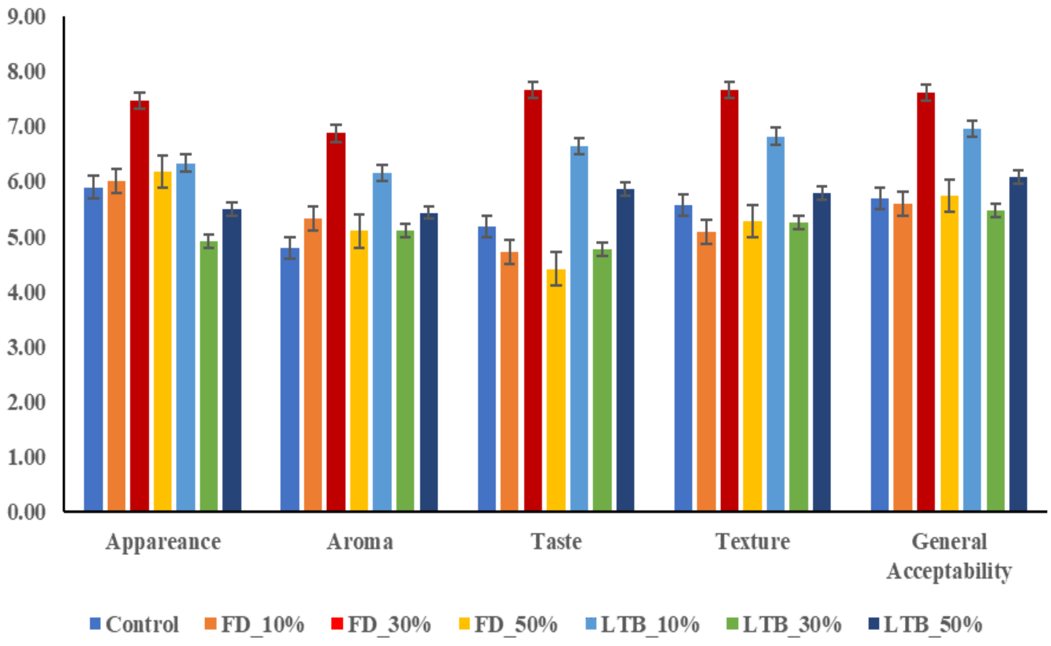


Figure 6.6: Sensory evaluation of noodles with different potato flour/wheat flour ratio

The texture of noodles substituted with freeze-dried potato flour at 30% and LTB_10% were the most preferred, while noodles substituted with LTB_OD potato flour at 30% and 50% were the least preferred. The texture in sensory evaluation is related to the noodles' firmness (hardness). Khouryieh et al. (2006) reported that the sensory scores, especially the texture of noodles, were comparable with the instrumental textural analysis (hardness in TPA profile). Texture analysis of noodles evaluates how firm or soft the noodles are, which differs from consumer to consumer. Some consumers prefer firm noodles, while others prefer soft ones. Wootton & Wills (1999) reported that Korean consumers prefer cooked noodles with a smooth texture, and there was a significant negative correlation between Korean consumer preferences and firmness.

6.4 Conclusion

This study evaluated the effect of substituting wheat flour with potato flour processed in different ways. The lightness (L*) decreases while yellowness (b*) increases, especially in the noodles made from LTB_OD flour blends. Cooking loss and weight of cooked noodles increased, which can be attributed to the dilution of gluten content and increase in starch content, respectively. When the proportion of potato flour reached 30%, the noodle textural quality, including hardness, cohesiveness, gumminess, and chewiness, decreased significantly ($p \leq 0.05$). Noodles made from 30 % freeze-dried flour gave the highest overall liking scores. Potato flour processed in different ways produced different quality noodles. Acceptable noodles were produced with 30% substitution with freeze-dried flour and 10% replacement with low-temperature blanched-oven dried potato flour.

CHAPTER SEVEN

CONCLUSION AND FUTURE PERSPECTIVES

7.1 General conclusion

This study aimed to assess the physicochemical properties of potato flour and its impact on functionality, with a specific focus on noodles production. Three main varieties of potatoes grown in Kenya were analyzed, and their flour was subjected to different pre-treatments and drying methods. The findings of this study indicate that Dutch Robjin variety recorded the highest percentage of peel loss (25%) while Unica recorded that the least (8%). It was concluded that Dutch Robjin has more eyes as compared to Shangi and Unica. It was also found that freeze-drying treatments yielded the highest percentage of flour, while Boiling_OD resulted in the lowest yield. Freeze-drying and LTB_OD led to lighter-colored flour than Boiling_OD and HTB_OD. Boiling_OD and HTB_OD exhibited good flow characteristics, making them suitable for easy mixing, transportation, and handling. This study’s findings highlight significant variations in protein, sucrose, and minerals contents among flour from different potato varieties subjected to different processing methods. Freeze drying exhibited higher protein content, sugars content as well as minerals retention in all the varieties. On the other hand, Boiling_OD potato flour showed the least retention of nutrients for all the varieties.

The study also revealed that the various processing methods significantly affected the particle size and microstructural properties of the potato flour. Freeze-drying produced flour with the smallest particle size and with native starch granules, whereas Boiling_OD, had damaged starch granules. Moreover, the swelling power and solubility index of the potato flour increased with higher processing temperatures, and these properties were strongly correlated with the particle size. The apparent viscosity of the potato flour was significantly reduced in Boiling_OD and HTB_OD, while freeze-dried flour recorded the highest peak viscosity, rendering it suitable for thickening soups. Boiling_OD and HTB_OD flours, on the other hand, would be ideal for weaning and supplementary foods due to their low setback viscosity, while LTB_OD showed potential for use in noodles.

The findings revealed that replacing wheat flour with freeze-dried flour led to a significant decrease in the mean particle size of the blended flour, while LTB_OD flour increased the mean particle size. Additionally, the inclusion of potato flour substantially increased the pasting properties of wheat flour, with freeze-dried flour blends exhibiting the highest pasting properties compared to LTB_OD flour blends. Microstructural analysis of the control sample (100% wheat dough) showed the presence of small and large starch granules tightly dispersed in a gluten network structure.

The addition of potato flour resulted in changes in color properties, with decreased brightness (L*) and increased redness (a*) and yellowness (b*) of the noodles. Moreover, the cooking loss of the noodles significantly increased with the incorporation of potato flour, with LTB_OD flour blends experiencing the highest loss. When the ratio of potato flour reached 30%, the textural properties of the noodles, including hardness, cohesiveness, gumminess, and chewiness, decreased significantly. Substituting up to 30% with freeze-dried flour resulted in noodles with the highest overall liking scores among the different formulations. This suggests that freeze-dried flour is a more favorable option for replacing wheat flour in instant noodle production.

This study highlights the potential of utilizing processed potato flours as partial replacements for wheat flour in noodle production, offering valuable insights into the physicochemical and sensory attributes of the resulting composite flours and noodles. These findings can contribute to the development of innovative and nutritious instant noodle products catering to consumer preferences and dietary needs.

7.2 Future perspectives

Based on the results of this study, there are several promising avenues for future research to further explore and improve the use of potato flour in food products. Some potential recommendations and future perspectives are as follows:

1. Further study on the effect of other flour processing methods such as microwave drying, sun drying, solar drying is necessary to expand the utilization window for potato flour.
2. Study the functionality of potato flours in different food products can be expanded to other foods such as baked products, extruded snacks, or other convenience foods could offer more diverse applications and insights into their potential benefits.
3. Assess nutritional and health benefits of potato flour and their products can be done *in vitro* and invivo to demonstrate the health benefits of such products.
4. Shelf-life stability studies are to guide processors and consumers.
5. Sustainability and economic considerations are necessary to determine the business viability of potato flour blends and their applications.

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APPENDICES

Appendix I: Images of potato varieties used in this study.

SHANGI

UNICA

DUTCH ROBJIN

Appendix II: Color characteristics for Unica and Dutch varieties

1. Unica variety

Samples	L*	a*	b*	Chroma	Hue
Oven drying (OD)	88.30±0.01^{b}	0.07±0.01^{d}	15.79±0.01^{c}	15.80±0.01^{c}	1.57±0.01^{a}
Blanching (60°C) _ OD	84.36±0.01^{c}	0,51±0.01^{b}	10,54±0.01^{d}	10,55±0.01^{d}	1,53±0.01^{b}
Blanching (95°C) _ OD	81.36±0.01^{e}	3.02±0.01^{a}	24.62±0.01^{b}	24.80±0.01^{b}	1.45±0.01^{b}
Boiling_OD	82.89±0.01^{d}	3.56±0.01^{a}	26.46±0.01^{a}	26.70±0.01^{a}	1.44±0.01^{b}
Freeze-drying (FD)	90.86±0.01^{a}	-0.31±0.01^{c}	15.19±0.01^{c}	15.20±0.01^{c}	- 1.55±0.01^{c}

Means within column followed by the same letter are not significantly different ($p<0.056$) from each other.

2. Dutch Robjin variety

Samples	L*	a*	b*	Chroma	Hue
Oven drying (OD)	92.12±0.01^{a}	-0.86±0.02^{c}	14.39±0.01^{e}	14.42±0.01^{e}	-1.51±0.01^{d}
Blanching (60°C) _ OD	86.08±0.01^{b}	0.50±0.01^{a}	16.59±0.01^{d}	16.60±0.01^{d}	1.54±0.01^{c}
Blanching (95°C) _ OD	85.68±0.01^{c}	0.11±0.01^{b}	20.96±0.01^{b}	20.97±0.01^{b}	1.57±0.01^{a}
Boiling_OD	81.16±0.01^{d}	0.55±0.01^{a}	25.56±0.01^{a}	25.57±0.01^{a}	1.55±0.01^{b}
Freeze-drying (FD)	92.76±0.01^{a}	-1.26±0.01^{d}	17.50±0.01^{c}	17.55±0.01^{c}	-1.50±0.01^{d}

Means within column followed by the same letter are not significantly different ($p<0.056$) from each other.

Appendix III: Bulking properties for Unica and Dutch varieties

1. Unica variety

Samples	Bulk density (g/mL)	Tapped density (g/mL)	True density (g/mL)
Oven drying (OD)	0.69 ± 0.15^{d}	0.93 ± 0.01^{b}	1.64 ± 0.01^{a}
Blanching (60°C) _ OD	0.76 ± 0.02^{c}	0.99 ± 0.02^{a}	1.64 ± 0.01^{a}
Blanching (95°C) _ OD	0.85 ± 0.01^{b}	$1.01\pm0.01_{a}$	1.65 ± 0.01^{a}
Boiling_OD	0.91 ± 0.01^{a}	1.05 ± 0.01^{a}	1.64 ± 0.01^{a}
Freeze-drying (FD)	0.53 ± 0.01^{e}	0.83 ± 0.01^{c}	1.55 ± 0.01^{b}

Means within column followed by the same letter are not significantly different ($p<0.056$) from each other.

2. Dutch Robjin variety

Samples	Bulk density (g/mL)	Tapped density (g/mL)	True density (g/mL)
Oven drying (OD)	0.70 ± 0.02^{d}	0.99 ± 0.01^{a}	1.64 ± 0.01^{a}
Blanching (60°C) _ OD	0.79 ± 0.01^{c}	1.02 ± 0.01^{a}	1.65 ± 0.01^{a}
Blanching (95°C) _ OD	0.86 ± 0.01^{b}	1.03 ± 0.01^{a}	1.64 ± 0.01^{a}
Boiling_OD	0.90 ± 0.01^{a}	1.02 ± 0.01^{a}	1.64 ± 0.01^{a}
Freeze-drying (FD)	0.50 ± 0.01^{e}	0.75 ± 0.02^{b}	1.48 ± 0.01^{b}

Means within column followed by the same letter are not significantly different ($p<0.056$) from each other.

Appendix IV: Compressibility Index and Angle of repose for Unica and Dutch varieties

1. Unica variety

Samples	CI (%)	Angle of repose (°)	Flow Description	Type of Flour
Oven drying (OD)	25.80±1.02^{b}	31.12±0.11^{b}	Poor	Cohesive
Blanching (60°C) _ OD	22.22±0.65^{c}	28.82±0.28^{c}	Fair to good	Non-cohesive
Blanching (95°C) _ OD	15.84±0.91^{d}	28.58±0.21^{c}	Good to excellent	Free-flowing (non-cohesive)
Boiling_OD	13.33±0.09^{d}	27.44±0.35^{d}	Good to excellent	Free-flowing (non-cohesive)
Freeze-drying (FD)	36.15±1.11^{a}	33.16±0.03^{a}	Very poor	Cohesive

Means within column followed by the same letter are not significantly different (p<0.056) from each other.

2. Dutch Robjin variety

Samples	CI (%)	Angle of repose (°)	Flow Description	Type of Flour
Oven drying (OD)	29.29±0.85^{b}	30.46±0.13^{a}	Poor	Cohesive
Blanching (60°C) _ OD	22.54±0.74^{c}	29.19±0.43^{c}	Fair to good	Non-cohesive
Blanching (95°C) _ OD	16.50±1.01^{d}	29.01±0.27^{c}	Good to excellent	Free-flowing (non-cohesive)
Boiling_OD	11.76±0.21^{e}	28.29±0.22^{d}	Good to excellent	Free-flowing (non-cohesive)
Freeze-drying (FD)	33.33±0.45^{a}	32.52±0.31^{a}	Very poor	Cohesive

Means within column followed by the same letter are not significantly different (p<0.056) from each other.

Appendix V: Questionnaire for sensory evaluation by students

Participation in the Taste Panel Trial is Voluntary

RECORDING SHEET

Date:................Taster Name(optional):............................Gender:....M [...]........F [...]

Age group (Please tick): <20:...............20-30:..........30-40:...........40-50:...............50-60 60

You are provided with coded cooked noodles. Please grade the samples on the scale of 1 to 9 by placing your score in the box under the sensory parameter next to each sample in the table. **Rinse your mouth with water provided before tasting, re-tasting and in between products, then evaluate the products in front of you**.

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

SAMPLE CODE	APPEARANCE (Color)	AROMA	TASTE/FLAVOR	TEXTURE (Mouthfeel)	GENERAL ACCEPTABILITY
A1					
A2					
A3					
A4					
A5					
A6					
A7					

In the last two weeks, about how often have you eaten noodles? (Tick where applicable)

- Not a single time...............
- once in two weeks......
- Once a week ....
- More than once a week...........
- Every day.....................

General comments (Anything to be improved): ....

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Appendix VI: List of Publications

1. List of Publications in International Peer-Reviewed Journals

Buzera, A., Nkirote, E., Abass, A., Orina, I., & Sila, D. (2023). Chemical and Pasting Properties of Potato Flour (Solanum tuberosum L.) in Relation to Different Processing Techniques. *Journal of Food Processing and Preservation*, 2023(March), 12. https://doi.org/10.1155/2023/3414760

Buzera, E. Gikundi, I. Orina, and D.Sila. "Effect of pre-treatments and drying methods on physical and microstructural properties of potato flour," *Foods*, vol. 11, no. 4, 2022. https://doi.org/10.3390/foods11040507

Evelyne, N. G., Daniel, N. S., Irene, N. O., & **Ariel, K. B.** (2021). Physico-chemical properties of selected Irish potato varieties grown in Kenya. *African Journal of Food Science*, *15*(1), 10–19. https://doi.org/10.5897/ajfs2020.2025

Gikundi, E. N., **Buzera, A. K.,** Orina, I. N., & Sila, D. N. (2022). Storability of Irish Potato (*Solanum tuberosum L.)* Varieties Grown in Kenya, Under Different Storage Conditions. *0123456789*.

Buzera, A. K., Adoyo, G. O., Nkirote, E. G., Orina, I. N., & Sila, D. N. (2021). Characterization of potato starch isolated from four potato varieties grown in Kenya. *The Seventh Africa Higher Education Week and RUFORUM Triennial Conference 6-12 December 2021*, *2021*(19), 242–248. http://repository.ruforum.org.

2. Contribution to International Conferences

Buzera, E. Gikundi, I. Orina, and D. Sila. "Effect of pre-treatments and drying methods on physical and microstructural properties of potato flour (2021). *Poster presentation* at the **11th World Potato Congress (WPC 2022**) in Dublin, Ireland. From May 30th to June 2nd, 2022.

Buzera, E. Gikundi, I. Orina, and D. Sila. Effect of pre-treatments and drying methods on physical and microstructural properties of potato flour (2022). *Virtual Poster presentation* at the **12th African Potato Association Triennial Conference (APA, 2022)** in Lilongwe, Malawi. From June 26th to July 1st, 2022.

Buzera, E. Gikundi, I. Orina, and D. Sila. Effect of Wheat Flour Substitution with Potato Flour on Texture and Sensory Properties of Instant Noodles (2023). *Poster presentation* at the **Green Food Technology (GFT 2023)** in Montreal, Canada. From May 18th to May 19th, 2023.