Hindawi
Journal of Food Processing and Preservation
Volume 2023, Article ID 3414760, 12 pages
https://doi.org/10.1155/2023/3414760

*Research Article*

# Chemical and Pasting Properties of Potato Flour (*Solanum tuberosum* L.) in relation to Different Processing Techniques

**Ariel Buzera [1,2] Evelyne Nkirote,[2] Adebayo Abass,[3] Irene Orina [2] and Daniel Sila[2]**

[1]*Faculty of Agriculture and Environmental Science, Université Evangélique en Afrique (UEA), P.O. Box 3323 Bukavu, Sud-Kivu/RD, Congo*
[2]*Department of Food Science & Technology, Jomo Kenyatta University of Agriculture and Technology (JKUAT), P.O. Box 62000-00200 Nairobi, Kenya*
[3]*International Institute of Tropical Agriculture (IITA), No. 25; Light Industrial Area, Mikocheni B, Dar es Salaam, Tanzania*

Correspondence should be addressed to Ariel Buzera; arielbuzera@gmail.com

Received 14 December 2022; Revised 6 March 2023; Accepted 16 March 2023; Published 29 March 2023

Academic Editor: Karthikeyan Venkatachalam



Processing potato tubers into flour can be done using various methods, which can impact the flour's nutritional and pasting properties. This study evaluated the effects of five different processing methods, namely, low-temperature blanching, followed by oven drying (LTB_OD), high-temperature blanching followed by oven drying (HTB_OD), boiling followed by oven drying (Boiling_OD), freeze drying (FD), and oven drying (OD), on the nutritional and pasting properties of potato flour derived from Shangi potato variety. The relationships between the nutritional and pasting properties were determined using Pearson's correlation and principal component analyses (PCA). The results indicated that freeze-dried flour exhibited higher protein content (10.17%), sucrose (88.87 mg/100 g), and magnesium (44.90 mg/100 g) content, while Boiling_OD flour showed the lowest protein (6.41%), sucrose (15.34 mg/100 g), and magnesium (35.55 mg/100 g) content. All 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 flour. Protein ($r = -0.92$), fiber ($r = -0.81$), and fat ($r = -0.83$) negatively correlated with the peak viscosity, while sugars (glucose ($r = 0.95$), fructose ($r = 0.93$), and sucrose ($r = 0.87$)) and phosphorus ($r = 0.86$) positively correlated with pasting properties. The first two principal components explained 90.2% of the total variance. Oven drying and freeze drying were in close proximity in the PCA score plot, indicating that these two flour types have similar chemical and pasting properties. In conclusion, the different processing methods altered the chemical and pasting properties of the flour, therefore influencing their potential use in the food industry. Considering the correlations established in this study, it is likely that chemical properties could be used to predict the pasting properties of potato flour.

## 1. Introduction

Potato is the world's fourth most important food crop after rice, wheat, and maize [1]. It is estimated that more than 20 million hectares of farmland are used to grow potatoes globally, and the global production of potatoes is roughly 366 million tons [2]. Therefore, the production of potatoes is important as a source of food and provides income for many households [3]. Furthermore, potatoes are a good source of important nutrients such as proteins, carbohydrates, minerals, antioxidants, and dietary fiber [4].

Potatoes are, however, a perishable commodity. Consequently, they must either be consumed within a short period or require cold storage [5]. Due to inadequate, expensive, and unevenly distributed cold store facilities in many developing countries, postharvest loss of potatoes is very high [6]. To reduce postharvest losses, fresh potato tubers can be processed into potato flour [7]. In addition to having a longer shelf life, the flour has lower transportation and storage costs [8]. Furthermore, potato flour is used for its unique properties that distinguish it from other plant-based flours [9].

Potato flour is prepared by cleaning, peeling, and slicing potato tubers, pretreatments (blanching, boiling, or soaking), drying, grinding, and finally, sieving the end product [10]. The procedure is standard and differs in the pretreatments and drying methods [11]. It has been reported that different methods of pretreatment and drying produce potatoes with different physical, chemical, and functional properties, as reported by various studies [7, 12]. Özdemir et al. [13] reported that freeze drying preserved the nutritional content of potato flour while improving its solubility and emulsifying properties. According to Bao et al. [12], a variety of drying methods, including oven, freeze, and ethanol drying, had an effect on 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 [14]. Therefore, potato flour can be processed differently for various applications in the food industry.

In the food industry, flour's pasting properties are useful in selecting their potential applications [15]. The texture, digestibility, and end-use of a food product are influenced by its pasting properties [16]. Liu et al. [17] found that flour's pasting properties are influenced by its nutritional composition, such as starch, protein, lipids, and fiber. Ocheme et al. [16] reported that the pasting attributes decreased as carbohydrates decreased. Protein affects the pasting properties by interacting with starch molecules and modifying their gelatinization behavior [18].

This study examined the chemical and pasting properties of potato flour processed in different ways. The processing methods include the following: blanching at low temperatures followed by oven drying (LTB_OD), blanching at high temperatures followed by oven drying (HTB_OD), and boiling and then oven drying (Boiling_OD), freeze drying (FD), and oven drying (OD). The study also correlated the nutritional properties and pasting properties of the different flour. This study will provide information about the potential end-uses of various types of flour based on their pasting profiles.

## 2. Materials and Methods

*2.1. Potato Flour Production.* Potato tubers were obtained from farmers in Nyandarua County, Kenya. The Shangi variety, the most preferred in the country, was selected and used for this study. Various pretreatments and drying methods were used to process potato tubers into flour Buzera et al. [7], as detailed in Figure 1. For the first batch, the potato tubers were washed, peeled, and sliced into 2 mm thickness before being placed in a deionized water solution containing 5% sodium metabisulfite for five minutes in order to prevent enzymatic browning. A portion of the slices was oven-dried (OD) (Memmert UF 110 model, Schwabach, Germany) for 48 hours at 50°C with constant airflow of 2 m/s. Another portion of the slices was freeze-dried (FD) for 48 hours in a freeze-dryer (Lyovapor L-200 Pro, BUCHI, Flawil, Switzerland).

Another batch of peeled and sliced potato tubers was pretreated (blanching and boiling) before oven drying. Thin slices were blanched at low temperature (LTB) (60°C) for 30 minutes and then oven-dried for 48 hours at 50°C. Another set of thin slices was blanched at high temperature (95°C) (HTB) for 1 min and then oven-dried for 48 hours at 50°C. The final batch of potatoes was boiled in distilled water for 30 minutes at 95°C and immediately cooled in ice water for 5 minutes. After boiling the potatoes, they were mashed with a potato masher and dried in an oven for 48 hours at 50°C. All dried potato slices were ground into flour using a professional-grade blender and passed through a 500 $\mu$m sieve. A polyethylene ziplock bag was used to store each type of flour at room temperature until further analysis.

*2.2. Proximate Composition.* The proximate composition of potato flour, including moisture, crude ash, crude fiber, protein, and fat contents, were performed according to AOAC methods 984.25, 945.38, 920.53, 920.86, and 983.23, respectively [19]. Crude protein content was measured using the semimicro-Kjeldahl method with a conversion factor of 6.25. The total carbohydrate was calculated by the difference method [19]. $\text{Total carbohydrate (\%)} = 100 - (\%\text{Moisture} + \text{Protein} + \text{Fat} + \text{Crude fiber})$. Each of these analyses was carried out in triplicate.

*2.3. Sugar Determination.* The concentrations of glucose, fructose, and sucrose were determined using the method described by Abong et al. [20] 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 (HS-200 5S). 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 $\mu$m pore size) before injecting 20 $\mu$L into an ultraflow 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) and then pumped through a normal phase Ultisil $NH_2$ column with a $6 \times 250$ 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/100 g.

*2.4. Mineral Content.* The contents of iron (Fe), zinc (Zn), magnesium (Mg), potassium (K), phosphorus (P), and calcium (Ca) in potato flour were determined by the AOAC [21] method. After preparative steps, which included mashing 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).

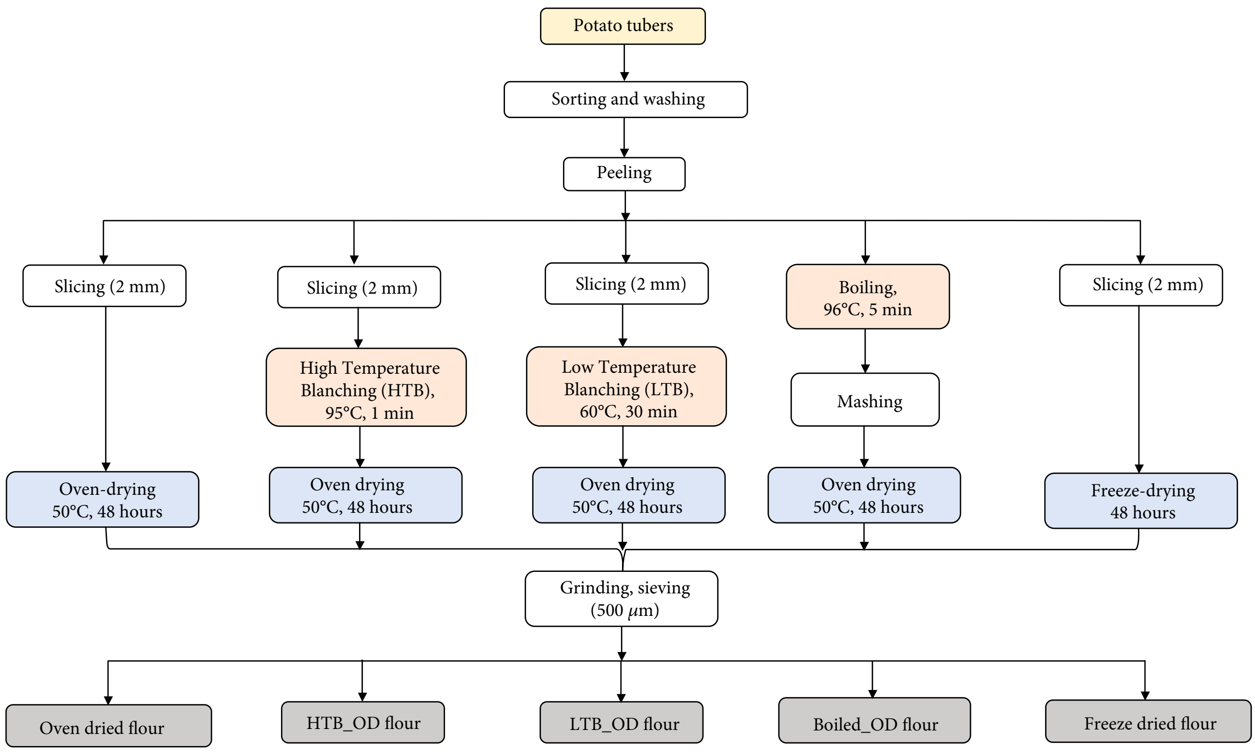


Figure 1: Schematic overview of the experimental set-up showing the five different flour types. OD: oven drying.

Mineral standards were used to quantify the minerals in potato flour. Mineral determinations were done in triplicate for each flour type.

*2.5. Apparent Viscosity.* The apparent viscosity of potato flour was determined using a technique described by Mohajan et al. [22] 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 speed at 6, 12, 30, and 60rpm, the viscosity was measured and recorded in Pa.s.

*2.6. Pasting Properties 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 et al. [23]. 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. A number of parameters were measured, including peak viscosity (Pv), breakdown viscosity (Bv), setback viscosity (Sv), final viscosity (Fv), peak time (minutes), and peak temperature (°C).

*2.7. Statistical Analysis.* Each measurement is averaged over 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. To examine the variations in potato flour's chemical and pasting properties resulting from different processing methods, principal component analysis (PCA) was applied using JAMOVI statistical software version 2.3.15.0.

## 3. Results and Discussion

*3.1. Proximate Analysis.* The results of the proximate composition analysis are presented in Table 1. Potato flour's moisture content ranged from 8.24% to 10.44%, which is acceptable for commercial flours. The highest moisture content was reported in freeze-dried and LTB_OD potato flour. Various factors can affect moisture content, including drying methods, drying times, and storage conditions [24]. According to Simsek [25], flour with a moisture content greater than 14% does not maintain its stability at room temperature. Potato flour with low moisture has a longer shelf life because it inhibits microbial growth and chemical reactions [26].

Table 1: Proximate composition of potato flour processed using different methods.

| Parameters | Oven drying | LTB_OD | HTB_OD | Boiling_OD | Freeze drying |
|---|---|---|---|---|---|
| Moisture (%) | $10.15 \pm 0.06^{b}$ | $10.33 \pm 0.02^{a}$ | $9.85 \pm 0.03^{c}$ | $8.24 \pm 0.02^{d}$ | $10.44 \pm 0.03^{a}$ |
| Protein ($N \times 6.25$) | $9.53 \pm 0.09^{b}$ | $9.26 \pm 0.12^{b}$ | $6.66 \pm 0.14^{c}$ | $6.41 \pm 0.08^{c}$ | $10.17 \pm 0.10^{a}$ |
| Ash (%) | $4.33 \pm 0.01^{a}$ | $4.22 \pm 0.06^{a}$ | $3.50 \pm 0.05^{c}$ | $4.01 \pm 0.01^{b}$ | $4.08 \pm 0.05^{b}$ |
| Fiber (%) | $1.51 \pm 0.02^{c}$ | $1.55 \pm 0.02^{bc}$ | $1.71 \pm 0.02^{ab}$ | $1.85 \pm 0.06^{a}$ | $1.51 \pm 0.09^{c}$ |
| Fat (%) | $0.32 \pm 0.03^{a}$ | $0.32 \pm 0.03^{a}$ | $0.09 \pm 0.01^{b}$ | $0.11 \pm 0.01^{b}$ | $0.36 \pm 0.02^{a}$ |
| Carbohydrates (%) | $74.15 \pm 0.18^{c}$ | $74.32 \pm 0.21^{c}$ | $78.69 \pm 0.22^{b}$ | $79.40 \pm 0.05^{a}$ | $73.43 \pm 10^{d}$ |

The results are the average of three measurements ± standard error. Different letters 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. Freeze-dried flour exhibited the highest protein content (10.17%), followed by oven drying (9.53%) and LTB flour (9.26%). Freeze drying preserves protein content more than other methods because it uses low pressure and temperature, which preserves cellular structure [26]. Yang [27] and Vaitkevičienė [28] reported higher values for freeze-dried potato flour of 13.06% and 12.1%, respectively. The low protein value in Boiling_OD and HTB_OD flours could be due to protein denaturation. Boiling would cause protein denaturation, hence a low protein level. Charged groups and nonpolar groups interact weakly at elevated temperatures, which disrupts their weak forces of attraction. As a result, the protein loses its tertiary structure [29]. The low protein content in Boiling_OD and HTB_OD could also be attributed to protein leaching during the cooking and blanching pretreatments, as reported by Hidayat and Setyadjit [11], who reported 32.08% of protein loss. According to Lakra and Sehgal [30], boiled, mashed potato flour contains 9.5% protein.

Ash content differed significantly among the five treatments. The ash content was higher in oven-dried (4.33%) and freeze-dried (4.08) potato flour and low in HTB_OD (3.50%) potato flour. Rahman et al. [31] reported similar results of 3.59% ash content for potato flour, while Hidayat and Setyadjit [11] 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 [28] for freeze-dried potato flour. The higher the ash content, the higher the mineral content of the flour.

The crude fiber of freeze-dried potato flour (1.51%) was not significantly different from oven-dried potato flour and LTB_OD potato flour. However, 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 [27, 32]. 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 [33]. Fiber facilitates bowel transit, reduces calorie consumption, and reduces diabetes incidence [26]. Moreover, it reduces glucose absorption, lowering blood sugar levels and carbohydrate metabolism [34]. 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. The fat content of freeze-dried (0.36%) and oven-dried flours (0.32%) 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 and Utami [35] 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 [36]. The different treatments significantly affected the carbohydrate content ($p < 0.05$). Freeze-dried potato flour had the lowest carbohydrate content (73.43%), while HTB_OD (78.69%) and Boiling_OD (79.40%) potato flour recorded the highest. This could be due to the high moisture content of freeze-dried flour in comparison to other flours. The amount of moisture lost during dehydration is inversely related to the amount of carbohydrates attained [26].

*3.2. Sugar Content.* Potato flour differed greatly in sugar content, with sucrose being the most prevalent sugar, followed by glucose and fructose (Table 2). The highest amount of sucrose was found in freeze-dried flour. 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 [37, 38]. This result agrees with Olatunde et al. [15], who found that blanching results in a reduction in sugars. Mestdagh et al. [39] indicated that a reduction in sugar content was observed when blanching temperatures were increased. Jangchud et al. [37] and Carillo et al. [40] reported that solids are leached from 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 [41]. This results in an overall decrease in

Table 2: Sugar contents of potato flour processed using different methods.

| Parameters | Oven drying | LTB_OD | HTB_OD | Boiling_OD | Freeze drying |
|---|---|---|---|---|---|
| Glucose (mg/100 g) | $11.55 \pm 0.17^{b}$ | $10.81 \pm 0.13^{c}$ | $8.50 \pm 0.11^{d}$ | $6.81 \pm 0.19^{e}$ | $15.73 \pm 0.49^{a}$ |
| Fructose (mg/100 g) | $28.21 \pm 0.22^{b}$ | $20.70 \pm 0.43^{c}$ | $14.54 \pm 0.41^{d}$ | $10.36 \pm 0.27^{e}$ | $32.00 \pm 0.60^{a}$ |
| Sucrose (mg/100 g) | $38.31 \pm 0.56^{b}$ | $31.69 \pm 1.33^{b}$ | $18.03 \pm 0.26^{c}$ | $15.34 \pm 0.06^{c}$ | $88.81 \pm 3.27^{a}$ |

The results are the average of three measurements ± standard error. The presence of different letters 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.

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 [42].

*3.3. Mineral Content.* The most abundant mineral was potassium (K), followed by magnesium (Mg) and phosphorus (P). Generally, freeze-dried potato flour exhibited high specific mineral content, followed by oven-dried flour. On the other hand, HTB_OD and Boiling_OD potato flour recorded the lowest specific mineral contents (Table 3). Mineral leaching during cooking may be responsible for the lowest mineral content recorded in HTB_OD and Boiling_OD potato flour [43].

The lowest Fe (1.35 mg/100 g) and Zn (0.62 mg/100 g) contents were reported in the Boiling_OD sample. In comparison with most cereals and legumes, potato flour contained lower amounts of iron and zinc [39]. 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 it [4]. In addition, potato iron is liberated from its matrix during in vitro gastrointestinal digestion and is, therefore, readily absorbed through the intestine [44].

The lowest K (223.70 mg/100 g) and Mg (35.55 mg/100 g) contents were, respectively, reported in the HTB_OD and Boiling_OD samples. Bethke and Jansky [45] reported that when potato tubers are boiled, the potassium and magnesium can dissolve in the cooking water, resulting in a loss of these nutrients. Additionally, certain forms of magnesium can convert into insoluble forms during boiling, which can lead to the loss of magnesium. For example, magnesium can react with phytic acid, a potato compound, to form insoluble magnesium phytate. This can reduce the bioavailability of magnesium in foods [46]. The same trends were observed for calcium and phosphorus.

*3.4. Apparent Viscosity.* The apparent viscosity of the five flour types evaluated in this study is shown in Figure 2. 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. Xiao et al. [47] reported that increasing the shear rate might result in a decrease in viscosity as a consequence of an increase in external force and the destruction of the hydration structure between polysaccharides and water molecules.

The highest viscosity values were found in freeze-dried and oven-dried potato flour, and the lowest was found in Boiling_OD and HTB_OD flour. Differences in apparent viscosity are attributed to differences in the chemical composition of the flours, particularly starch and protein [48]. Protein denaturation and starch gelatinization of the flour during processing affect their functional properties. As a consequence of starch gelatinization and protein denaturation, respectively, during blanching and cooking, HTB_OD and Boiling_OD potato flours have low apparent viscosities [48]. Therefore, it is suggested that freeze-dried potato flour may be used as a food thickener because of its higher viscosity [49].

*3.5. Pasting Characteristics.* The effects of different processing methods on potato flour's pasting properties are shown in Table 4 and Figure 3. Pasting properties indicate the molecular degradation of flour, as well as the degree of paste viscosity and stability [50]. The peak viscosity (Pv) of the different flours ranged from 1921.33 cP to 7098.33 cP. Peak viscosity indicates that starch granules can swell freely before they physically dissolve [51].

The highest peak viscosity value was recorded for freeze-dried potato flour (7098.33 cP), while Boiling_OD recorded the lowest (1921.33 cP). This result agrees with the findings on the apparent viscosity (Figure 2), where freeze-dried flour had the highest apparent viscosity. Flour with a high peak viscosity has a high thickening capacity [50]. It is, therefore, possible to use freeze-dried flour to thicken food products. On the other hand, the low peak viscosity observed in Boiling_OD flour is attributed to starch gelatinization during flour processing. Therefore, Boiling_OD flour could be utilized in preparing weaning and supplementary foods.

When flours undergo constant temperature and mechanical shearing stress, they develop trough viscosity (Tv). This is a measure of the starch granules' resistance to breakdown after prolonged exposure to high temperatures [52]. 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 a stable 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, we can estimate how well the paste resists disintegration when heated and sheared [52]. Freeze-dried flour recorded the highest breakdown viscosity

Table 3: Mineral content of potato flour processed using different methods.

| Parameters | Oven drying | LTB_OD | HTB_OD | Boiling_OD | Freeze drying |
|---|---|---|---|---|---|
| Fe (mg/100 g) | $1.62 \pm 0.03^{a}$ | $1.57 \pm 0.11^{b}$ | $1.35 \pm 0.04^{c}$ | $1.35 \pm 0.06^{c}$ | $1.73 \pm 0.06^{a}$ |
| Zn (mg/100 g) | $0.75 \pm 0.01^{b}$ | $0.72 \pm 0.01^{cd}$ | $0.71 \pm 0.01^{d}$ | $0.62 \pm 0.02^{c}$ | $0.79 \pm 0.04^{a}$ |
| Ca (mg/100 g) | $12.03 \pm 0.32^{b}$ | $11.95 \pm 0.03^{b}$ | $11.10 \pm 0.34^{c}$ | $11.45 \pm 0.15^{bc}$ | $13.54 \pm 0.21^{a}$ |
| P (mg/100 g) | $43.78 \pm 0.13^{b}$ | $42.21 \pm 0.04^{c}$ | $22.16 \pm 0.01^{e}$ | $27.53 \pm 0.10^{d}$ | $47.15 \pm 0.53^{a}$ |
| K (mg/100 g) | $232.74 \pm 1.19^{ab}$ | $230.59 \pm 1.19^{b}$ | $223.70 \pm 0.99^{c}$ | $231.82 \pm 1.19^{b}$ | $255.95 \pm 1.59^{a}$ |
| Mg (mg/100 g) | $43.54 \pm 0.05^{a}$ | $40.30 \pm 0.42^{b}$ | $38.70 \pm 1.72^{c}$ | $35.55 \pm 0.06^{d}$ | $44.90 \pm 0.32^{a}$ |

The results are the average of three measurements ± standard error. The presence of different letters 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.

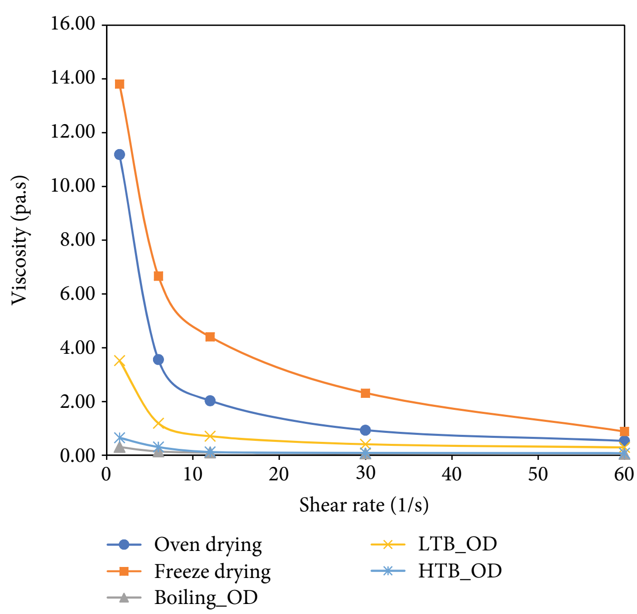


Figure 2: Apparent viscosity of potato flour processed using different processing methods.

compared to the other flour types. When the breakdown viscosity of the starch granules is increased that indicates 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 [53]. 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 [51].

Final viscosity is an indication of the ability of starch to form a viscous paste after it is cooked and cooled [54]. 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. [55]. 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 [56]. 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.

*3.6. Pearson Correlation Analysis.* Correlation analysis provided insights into the relationships between potato flour's chemical composition and pasting properties (Table 5). 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 Yuan et al. [57] stated. In addition, Yuan et al. [57] 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 [58].

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

Table 4: Pasting properties of potato flour processed using different methods.

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

The results are the average of three measurements ± standard error. The presence of different letters 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.

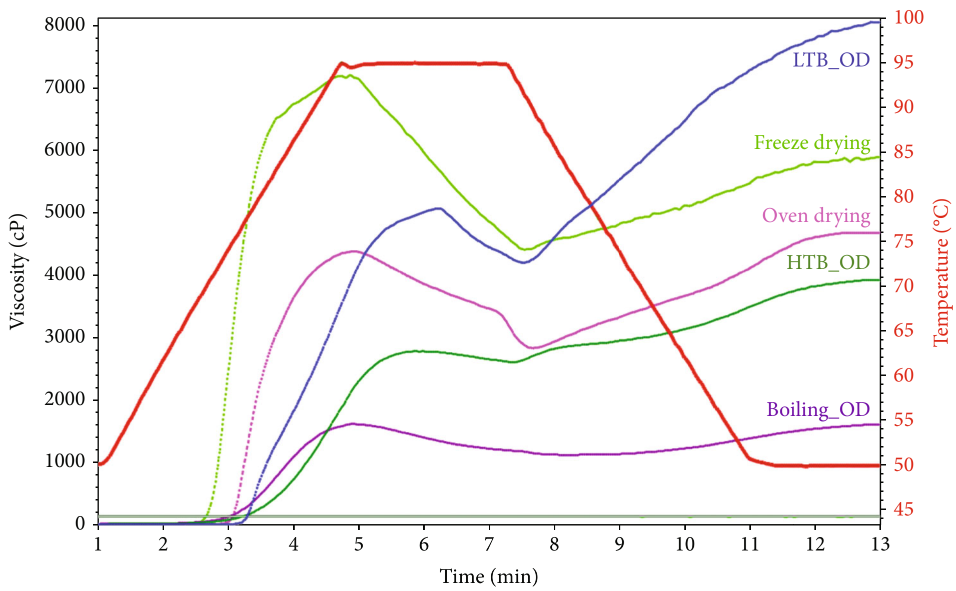


Figure 3: Pasting profile of potato flour processed using different methods.

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 [59].

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 due to the fact that 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 [60]. Sun et al. [61] 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 ($r = -0.56$, $p < 0.05$), and 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 [62]. It is important for food manufacturers and bakers to understand the relationship between sugars and flour pasting properties in order 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 [63]. Magnesium ions, on the other hand, can weaken the gel network by competing with calcium binding sites on the starch molecules [64]. Consequently, peak viscosity may be lower, and setback viscosity may be higher.

Table 5: 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 |
| Fiber | -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: $^{*}p < 0.05$, $^{**}p < 0.01$, and $^{***}p < 0.001$.

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. [65] 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 [66]. Noda et al. [67] reported a significant correlation between phosphorus content and pasting properties.

*3.7. Principal Component Analysis (PCA).* PCA was used to depict the link between the chemical and pasting characteristics of potato flour (Figures 4 and 5). The principal component analysis (PCA) involves the reduction of variables into a few orthogonal variables (principal components) without the loss of relevant information [68]. In this study, fourteen principal components (P1-P14) explained the variance in the data, with the first two principal components accounting for 90.2% of the total variance.

HTB_OD and Boiling_OD potato flours had a large negative scope in PC1, while freeze-dried flours had large positive scores in PC1. Conversely, LTB_OD had a large positive scope in PC2. Oven drying and freeze drying were in close proximity, indicating that they have similar chemical and pasting properties. Conversely, Boiling_OD is located on the opposing side to freeze drying and oven drying.

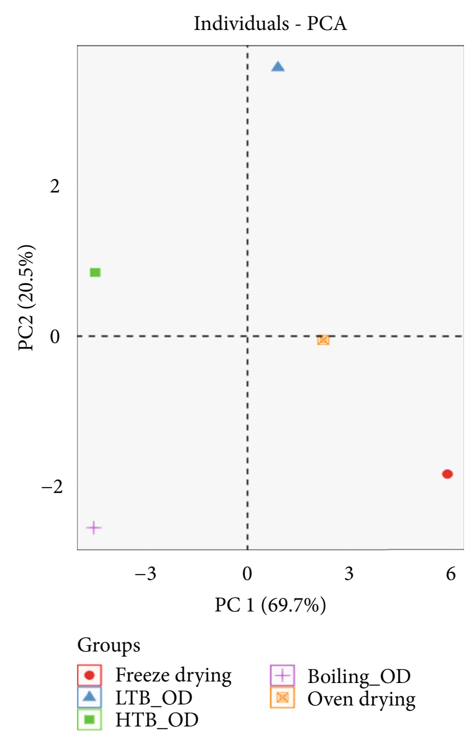


Figure 4: Score plots of PC1 and PC2 indicate the overall variation between potato flours processed using different methods.

The first component (PC1) accounted for 69.7% of the total variance, with the significant properties of moisture, protein, fiber, carbohydrates, peak viscosity, trough viscosity,

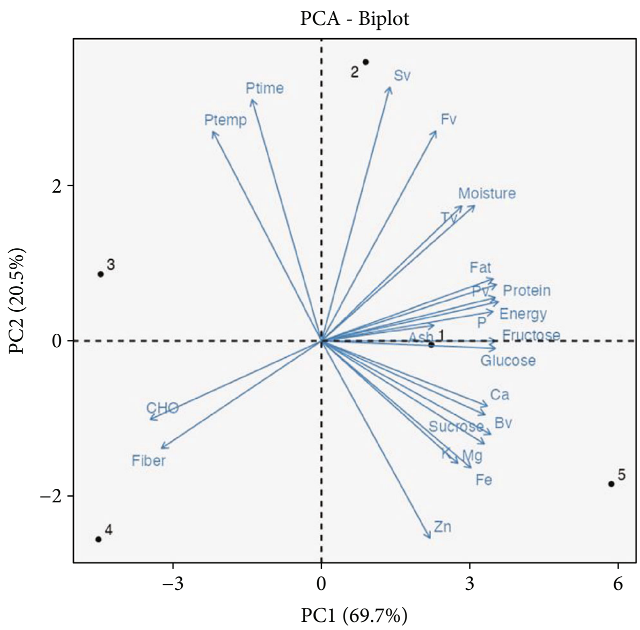


Figure 5: Principal component analysis: loading plot of PC1 and PC2 describing the variations of chemical and pasting properties of potato flour prepared by different drying methods. (Pv: peak viscosity, Tv: trough viscosity, Sv: setback viscosity, Fv: final viscosity, Bv: breakdown viscosity, Ptem: pasting temperature, Ptime: peak time).

final viscosity, and setback viscosity. Approximately 20.5% of the variance was accounted for by the second component (PC2), which was primarily determined by pasting temperature and peak time. The correlation between variables in pairs or groups indicates a positive correlation, whereas the correlation between variables in opposite directions indicates a negative correlation [69]. As shown in Figure 5, protein content, phosphorous, and fat were positively correlated with peak viscosity. Carbohydrate and fiber content negatively correlated with most of the pasting properties studied.

## 4. Conclusion

This study reported that different processing methods influence the chemical and pasting properties of potato flour. Freeze-dried potato flour exhibited higher chemical composition compared to potato flours obtained by other processing methods studied. 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. 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. Protein, fiber, and fat were negatively correlated with peak viscosity. On the other hand, sugars (sucrose, glucose, and fructose) had a positive correlation with peak viscosity ($r = 0.95$, $r = 0.93$, and $r = 0.87$, respectively), breakdown viscosity ($r = 0.93$, $r = 0.92$, and $r = 0.95$, respectively), and final viscosity ($r = 0.62$, $r = 0.52$, and $r = 0.43$, respectively). A positive correlation was observed between potato flour's phosphorus, magnesium, and calcium contents, except when it came to pasting temperature. PCA shows that freeze-dried and oven-dried potato flour have similar chemical and pasting properties. The various correlations established in this study indicated chemical properties such as protein, fat, carbohydrates, fibers, 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.

## Data Availability

Please contact the corresponding author if you would like access to any of the data included in this study.

## Conflicts of Interest

The authors of this article have declared no conflicts of interest.

## Authors' Contributions

Ariel Buzera was involved in the conceptualization, data curation, formal analysis, and writing—review and editing. Evelyne Nkirote was involved in the review and editing. Adebayo Abass was involved in the review and editing. Irene Orina was involved in the conceptualization, supervision, review, and editing. Daniel Sila was involved in the supervision, finding acquisition, review, and editing.

## Acknowledgments

This research is supported by Japan International Cooperation Agency (JICA) (AFRICA-ai-JAPAN project-phase 2) and Regional Universities Forum for Capacity Building Agriculture (RUFORUM) through the Graduate Training Assistantship Program. We would like to express our gratitude to Université Evangélique en Université Afrique (UEA) for providing subsistence and academic leave to the Ph.D. student.

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