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Impact of Some Processing Factors on the Pasting Properties of Poundo Flour Made From Precooked Sweet Potato Tubers

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ABSTRACT: Understanding the impact of processing factors on the pasting properties of flour is critical for optimizing its quality, functionality, and suitability for various food applications. This study investigated the effect of three processing factors: slice thickness, precooking time, and drying temperature on the pasting properties of poundo flour made from precooked tuber crops (sweet potato) using a 3 × 5 central composite rotatable design. Pasting properties, including peak viscosity (PV), final viscosity (FV), trough viscosity (TV), setback viscosity (SBV), breakdown viscosity (BDV), and pasting time (Pt), were analyzed. The measured values ranged as follows: PV (192.46–281.36 RVU), FV (211.37–298.25 RVU), TV (75.3–99.37 RVU), BDV (114.03–195.99 RVU), SBV (116.09–210.97 RVU), and Pt (3.86–6.44 min). The coefficients of determination of the PV, FV, TV, BDV, SBV, and Pt were 0.96, 0.94, 0.80, 0.95, 0.93, and 0.78, respectively. High coefficients of determination indicated strong correlations between processing factors and pasting properties. Optimization aimed to maximize viscosities while minimizing Pt. Predicted optimum values of 281.36 RVU (PV), 283.81 RVU (FV), 90.90 RVU (TV), 190.71 RVU (BDV), 193.16 RVU (SBV), and 4.54 min (Pt) were obtained at 2.51 mm slice thickness, 21.38 min precooking time, and 64.79°C drying temperature. This was experimentally validated to give corresponding values of 282.36 RVU, 282.21 RVU, 91.04 RVU, 190.22 RVU, 193.59 RVU, and 4.46 min, respectively. The developed models could be used to select any combination of the processing parameters that will suit the pasting properties of poundo flour made from precooked sweet potato tubers.

Practical Application

By carefully controlling and understanding the processing factors that influence the pasting properties of poundo flour made from precooked sweet potato tubers, the food industry can create high-quality, versatile, and nutritious products that meet diverse consumer needs and preferences. For instance, understanding the pasting properties of poundo flour allows for the development of gluten-free breads, cakes, and other baked items. Another application is in the formulation of convenient, shelf-stable porridge or weaning foods for infants and young children. Additionally, the pasting properties of poundo flour could be leveraged in producing value-added sweet potato–based snacks or extruded products. Food manufacturers can optimize pasting properties to produce poundo flour with desirable consistency and texture to improve the final product quality, making it more appealing to consumers. Furthermore, food service providers can select poundo flour with specific pasting properties that best suit different recipes like soups, sauces, or doughs, enhancing the culinary experience.

Abbreviations: BDV, breakdown viscosity; CCRD, central composite rotatable design; DT, drying temperature; FV, final viscosity; PRt, precooking time; Pt, pasting time; PV, peak viscosity; RSM, response surface methodology; RVA, Rapid Visco Analyzer; SBV, setback viscosity; ST, slice thickness; TV, trough viscosity; WFSP, white-fleshed sweet potato.

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1 | Introduction

Sweet potato (*Ipomoea batatas* (L.) Lam) is an important root crop that belongs to the division Magnoliophyta, class Magnoliopsida, order Solanales, and family Convolvulaceae (Jiang et al. 2022). It is cultivated in many countries across the tropical, sub-tropical, and temperate regions and serves as the primary dietary staple in Africa, Asia, the Caribbean, and South America. It is a vital source of carbohydrates, vitamins A and C, fiber, iron, potassium, and protein (Kaur and Sandhu 2016). It is one of the most significant, adaptable, and underutilized food crops in the world, producing about 90 Mt annually, primarily from Asian and African countries (Alam 2021). Sweet potato is the sixth most important food crop globally and the fifth most economical after rice, wheat, maize, and cassava (Alam 2021; Escobar-Puentes et al. 2022). Apart from being nutritious, they have also been found to be a functional food that contains significant amounts of phytochemicals, which may have numerous positive benefits on health (Ji et al. 2015). Sweet potato is eaten boiled, fried, baked, or roasted and is used to make several formulated products, such as noodles (Kadiri et al. 2020), porridge (Kruger 2020), snack bars (Natabirwa et al. 2020), soup (Omoba et al. 2020), bread (Oloniyo et al. 2021), cookies (Adeola and Ohizua 2018), yogurt (Donkor et al. 2020), beverages (Weber et al. 2020), juice (Park et al. 2020), beer (Humia et al. 2020), and vinegar (Wu et al. 2017). It can also be processed into crisps and flour, which is used for baking on its own or as a supplement to cereal flour (Jia et al. 2023; Nduka 2024), and as a fat replacer (Surendra Babu et al. 2018) and stabilizer (Aysha et al. 2017) in the ice cream industry. In Nigeria, boiled sweet potato is made into a pounded form and eaten with soup. It is also added to yam to prepare pounded yam (Ariyo et al. 2021).

Despite the various applications of sweet potato in formulated products, it is highly perishable and challenging to store for a longer duration. This is mostly because of their thin, permeable skin, high moisture content, and metabolic activity after harvesting, which makes them susceptible to damage during storage (Ren et al. 2021). Sweet potatoes have a variable shelf life, ranging from a few days to several weeks, depending on the cultivar, harvesting conditions, and storage conditions (Mtunda et al. 2001). This causes wastage, and it is a major barrier to the optimal use of the crop. Consequently, there are benefits to processing sweet potatoes into a form that can be preserved, including fewer post-harvest losses, increased financial returns, convenience, and improved nutrition (Chen et al. 2024; Flores 2017; Vithu et al. 2019). In general, processing aids in product preservation and year-round availability. Considering this, sweet potato can be made into a convenient and versatile flour suitable for various culinary applications such as poundo flour. Poundo flour is a flour made from fermented and dried sweet potatoes, commonly used in West African cuisine (Ajayi et al. 2016). It is rich in carbohydrates, providing a good source of energy. It also contains dietary fiber, vitamins (such as vitamin C and some B vitamins), and minerals (like potassium and magnesium) (Oluwole et al. 2012; Oyeyinka et al. 2023). The conversion of sweet potatoes to poundo flour involves several operations to ensure the final product is of high quality, retaining the nutritional benefits and desired textural properties. These operations include sorting, washing, peeling, slicing, soaking, precooking, drying, cooling, milling, sieving, and packaging, as shown in Figure 1. Poundo flour is instant flour produced by drying precooked tuber crops, milling, and sieving to a fine powder. It is a quick method of preparing a pounded form of tuber crops by adding a certain quantity of poundo flour to boiling water and stirring continuously until the desired texture and flavor are reached (Peter et al. 2012). In order to obtain good cooking quality and texture, the pasting characteristics of the flour need to be considered.

Pasting properties of flour refer to the gelatinization and subsequent behavior of starch granules when flour is heated in the presence of water. Given that it influences the texture, digestibility, and end use of starch-based food commodities, it is among the most significant properties that impact quality and aesthetic considerations in the food industry (Adebowale et al. 2005). These properties affect the texture, digestibility, and end use of the food product (Ocheme et al. 2018). Upon mixing flour with water, the starch granules in the flour start swelling and absorbing the water. As the temperature increases, there is a continuous swelling of the starch granules, which causes the mixture to thicken or "paste." In order to evaluate the pasting properties of flours, several analytical instruments, including a Rapid Visco Analyzer (RVA), amylograph, and dynamic rheometer equipped with a starch pasting cell, have been used (Park et al. 2019; Srichuwong et al. 2017). RVA has been utilized to measure the pasting profile of flour, providing useful information on the flour's peak viscosity (PV), trough viscosity (TV), breakdown viscosity (BDV), final viscosity (FV), setback viscosity (SBV), and pasting time (Pt) (Batey and Curtin 2000; Nawaz et al. 2016; Oyeyinka et al. 2023; Ravi et al. 1999; Wireko-Manu et al. 2014). These pasting characteristics are important in determining how the flour will perform in applications like baking, thickening sauces and gravies, and producing other starch-based food products (Nikolić et al. 2022; Zhou et al. 2021; Zhu et al. 2020). The PV is the maximum viscosity reached by the flour–water mixture during the heating and holding process. It is influenced by the starch content and granule size of the flour. The TV refers to the minimum viscosity of the flour–water mixture observed during the heating and holding stage of the pasting profile analysis. After the flour–water mixture reaches its PV, the continued heating and shear forces can cause the starch granules to break down, leading to a decrease in viscosity. The point at which the viscosity reaches its minimum value is known as the TV. The BDV is the decrease in viscosity that occurs after the PV is reached, as the starch granules begin to break down under continued heating and shear. The FV is the viscosity of the flour–water mixture after it has been cooled down and is influenced by the extent of starch gelatinization and retrogradation. The SBV is the increase in viscosity that occurs during the cooling of the flour–water mixture. It is related to starch retrogradation and can affect the texture of the final product. The Pt is the time required for the flour to gelatinize and reach its maximum viscosity when heated in the presence of water (Batey and Curtin 2000; Wang et al. 2015).

The pasting characteristics of starches have been associated with cooking quality and texture of a variety of food products (Otegbayo et al. 2006). Several factors influence the pasting properties of thermally processed starchy materials or foods, which include the flour's starch composition, particle size, moisture content, heating temperature, and thermal processing time, among others (Liu et al. 2022). To this end, this study was therefore

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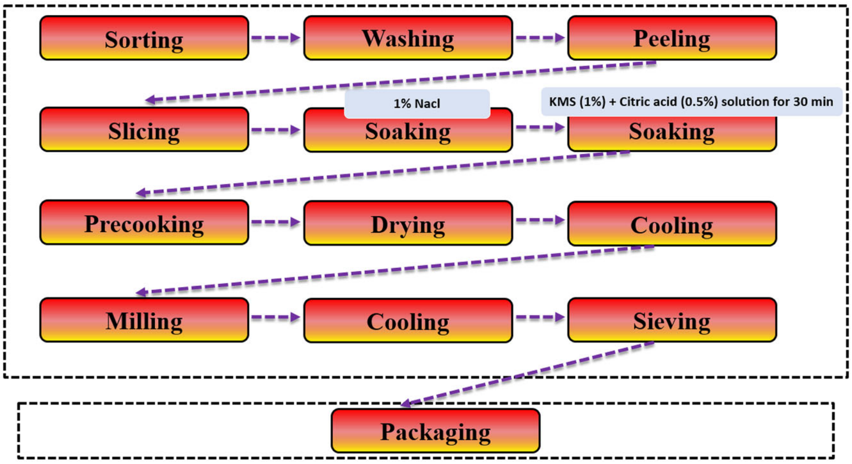

FIGURE 1 | Unit operations in the production of poundo flour from white-fleshed sweet potato.

undertaken to study the impact of some selected processing factors on the pasting properties of flour (poundo flour) made from precooked sweet potato tubers using optimization techniques. The approach used in this work studied the individual and interactive effects of the processing factors on the pasting properties of the flour. Response surface methodology (RSM), artificial neural networks (ANNs), genetic algorithms (GAs), and one-variable-at-a-time (OVAT) are some of the techniques that can be used for optimization. However, RSM is particularly effective at examining the interactions of selected independent variables on the desired response(s), particularly when there may be synergistic or antagonistic effects between the independent variables (Fakayode et al. 2019). It has several advantages such as efficient use of resources, ability to optimize, ability to model non-linear relationships, flexibility in design, and robust analysis of interaction effects, among others. RSM has been utilized in many food processing applications such as cooking (Bepary and Wadikar 2018), drying (Kumar et al. 2014), baking (Okpala and Okoli 2013), fermentation (Pradhananga 2019), frying (Turan et al. 2022), roasting (Raigar et al. 2017), extrusion (Yağcı and Göğüş 2008), oil expression (Fakayode and Ajav 2016), and product formulations (Felberg et al. 2010; Peerkhan and Nair 2021; Pintor et al. 2014), among others. Thus, this study used RSM for optimizing the effect of slice thickness, precooking time, and drying temperature on the pasting properties of poundo flour made from precooked sweet potato tubers.

2 | Materials and Methods

2.1 | Sample Procurement and Equipment Used

The sweet potato used for this study was a freshly harvested white-fleshed sweet potato (WFSP) (*Hannah variety*) procured from Kure Market, Minna, Niger State, Nigeria. The equipment used include RVA (Newport Scientific RVA, Sydney, Australia), a dehydrator, a slicer, an air oven (Uniscope SM9053, Surgifriend Medicals England, 50°C–300°C), an electronic weighing balance (Sartorius, England Mark, Serial Number PT210, capacity 1–200 g, sensitivity 0.01 g), heating devices (heating devices Kjeldatherm, Easy Way Medical England, England Make, Serial Number 7731 408), a blender, and a grinding machine. The reagents used are potassium metabisulfite (KMS), potassium hydroxide (KOH), sodium hydroxide (NaOH), alcohol (ethanol), and dilution media. All reagents are of analytical grade, with a purity of ≥99%.

2.2 | Production of Sweet Potato Flour

The sweet potatoes were inspected manually and sorted to remove all extraneous materials, such as any damaged, rotten, or foreign materials like stones, leaves, and so forth. Two kilograms of the sweet potatoes were weighed; the tubers were washed thoroughly to remove sand particles and dirt and were thereafter peeled in water to avoid discoloration of the peeled tubers. The peeled tubers were sliced (slice thicknesses, 1–5 mm) and directly immersed into 1% NaCl solution as well as immersed in a solution containing KMS (1%) and citric acid (0.5%) for 30 min to prevent enzymatic browning, preserve color and quality, reduce microbial load, and improve shelf life. The pretreated slices were precooked in water (precooking times, 5–25 min) before drying (drying temperatures, 40°C–80°C). Drying was carried out on perforated trays using a 12-tray dehydrator until the slices reached a moisture content of 7%–8%. After drying, the slices were cooled on the trays before being milled into flour using a blender. The resulting flour was then sieved through an 80-mesh sieve to achieve a uniform particle size. Finally, the flour was packed in airtight nylon bags for subsequent analyses.

2.3 | Determination of Pasting Properties

RVA was used to determine the pasting properties of the samples. 3.5 g (dry weight) of each of the samples and 25 mL of distilled water were added into the RVA canister. A paddle was inserted into the water and sample-filled canister, and the paddle blade was energetically jogged through the sample up and down seven times, after which the sample was placed in the RVA. The slurry was heated at a temperature of 50°C to 95°C for 2 min, then it was cooled to 50°C for the same time duration of 2 min. From the pasting profile, the PV, FV, TV, BDV ($PV - TV$) and SBV ($FV - TV$), and Pt were recorded. This was conducted three times and repeated for all the samples.

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2.4 | Experimental Design

The effects of the processing conditions, namely, slice thickness, precooking time, and drying temperature, on the pasting properties of the sweet potato flour were investigated. The experimental matrix generation, model fitting, and response surface analysis were carried out using the Design Expert 22.0 software package (Stat-Ease Inc., Minneapolis, USA). A 3 × 5 (three independent variables with five factors) central composite rotatable design (CCRD) was employed to systematically optimize the experimental parameters and analyze their effects. This design involved 20 experimental runs, including a 2^3 factorial central composite design (CCD), 6 axial points ($\alpha = 2$), and 6 center point replicates. The factorial component was utilized to evaluate both linear and interaction effects of the variables, whereas the axial points provided insight into the curvature of the response surface. The replicates at the center points improved the model's accuracy and reliability by estimating the experimental error. The rotatability of this design ensured uniform prediction variance across the experimental domain, enabling the creation of a robust and reliable predictive model. For the independent variables, slice thickness of 1–5 mm (1 mm interval), precooking time of 5–25 min (5 min interval), and drying temperature of 40°C–80°C (10°C interval) were selected on the basis of preliminary experiments, observations, and literature.

2.5 | Statistical Analyses

The optimization experimental results were statistically analyzed using Design Expert version 22.0 with a significance level of ($p < 0.05$). Analysis of variance (ANOVA) was conducted to evaluate the model's significance, fitness, and the impact of significant individual factors as well as their interactions on the pasting properties. The p value was used to assess the significance of each regression coefficient and to determine the interaction effects of the cross-product terms.

3 | Results and Discussion

3.1 | Effect of Processing Factors on the Pasting Properties of the Poundo Flour

The results obtained for the pasting properties of the poundo flour from WFSP are presented in Table 1. The variety, growth conditions, processing techniques, and measuring parameters, among other factors, are the reasons why these results inherently differ from those reported in the literature. Different values of pasting properties have been reported for a wide range of agricultural and food products, as well as across different varieties (Nikolić et al. 2022; Oduro et al. 2000; Ragaee and Abdel-Aal 2006; Tappiban et al. 2020; Zhou et al. 2021). It should be noted that the pasting properties are influenced by several factors, including starch composition, the amylose-to-amylopectin ratio, moisture content, and the specific processing conditions applied (Abioye 2012; Ahmed and Thomas 2017; Karakelle et al. 2020). The presence of other components like proteins, lipids, and fiber also plays a significant role in altering pasting behavior and, consequently, the results obtained (Fan et al. 2019; Wang et al. 2017). In addition, the storage conditions before processing can lead to variations in moisture content, which significantly affects viscosity measurements (Adekoyeni et al. 2018; Katekhong and Charoenrein 2012). The measurement parameters, such as the type of equipment used and the conditions under which the analysis is conducted, can also contribute to differences in the reported values (Balet et al. 2019; Ravi et al. 1999). The RVA, for instance, provides real-time data on viscosity changes, but even minor differences in sample preparation or test conditions can result in varying results. Finally, variations in temperature, drying methods, and particle size during processing can also cause fluctuations in pasting properties (Abioye 2012; Korese and Achaglinkame 2022). The results obtained from the effect of slice thickness, precooking time, and drying temperature on the PV, FV, TV, BDV, SBV, and Pt are discussed in the following section.

3.1.1 | Effect of Processing Factors on the PV

PV is a measure of the ability of starch to form a paste, and it indicates the highest value of viscosity during the heating cycle (Jimoh et al. 2009). It is the highest viscosity attained when the temperature rises above the pasting temperature (Leon et al. 2010), and it reflects the strength of pastes formed from gelatinization during food processing. It also shows the degree of granule swelling and the viscous load that will probably be encountered when mixing (Liang and King 2003). The highest PV value of 281.36 RVU was obtained when WFSPs were sliced at 2 mm thickness, precooked for 20 min, and dried at a temperature of 70°C; however, the lowest PV value of 192.46 RVU was obtained at a slice thickness of 5 mm, precooked for 15 min, and dried at a temperature of 60°C. As slice thickness increased from 1 to 3 mm at precooking time 15 min and drying temperature of 60°C, there was a moderate decrease in PV value of the flour by 5.26%. At the same pretreatment conditions, there was also a significant decrease of PV value by 24.45% as slice thickness increased from 3 to 5 mm. An increase in precooking time from 5 to 15 min at a slice thickness of 3 mm and drying temperature of 60°C significantly increased the PV value by 30.16%. Increasing the precooking time from 15 to 25 min at the same pretreatment conditions also increased the PV value by 8.39%. A significant increase in PV value by 16.57% was observed when the drying temperature was increased from 40°C to 60°C at a slice thickness of 3 mm and a precooking time of 15 min. However, a decrease of 7.50% was observed when the drying temperature was increased from 60°C to 80°C at the same pretreatment conditions.

3.1.2 | Effect of Processing Factors on the FV

FV is the most generally used parameter for assessing the quality of starch-based flour, and it shows the capacity of the starch to form a viscous gel or paste following the cooking and cooling phase (Ashogbon and Akintayo 2012). The highest FV value of 298.25 RVU was obtained when WFSPs were sliced at 3 mm thickness, precooked for 15 min, and dried at a temperature of 60°C; however, the lowest FV value of 211.37 RVU was obtained at a slice thickness of 1 mm, precooked for 15 min, and dried at a temperature of 60°C. As slice thickness increased from 1 to 3 mm at precooking time 15 min and drying temperature of 60°C, there

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TABLE 1 | The pasting properties of the poundo flour.

Run	ST	PRt	DT	PV	FV	TV	BDV	SBV	Pt
1	3.00	15.00	60.00	254.19 ± 0.450	298.25 ± 0.431	88.16 ± 0.441	166.03 ± 0.664	210.09 ± 0.831	5.40 ± 0.170
2	4.00	10.00	50.00	198.37 ± 0.505	228.66 ± 0.321	82.70 ± 0.446	115.67 ± 0.295	145.96 ± 0.338	6.44 ± 0.030
3	3.00	25.00	60.00	276.13 ± 0.260	283.37 ± 0.469	92.82 ± 0.334	183.31 ± 0.478	190.55 ± 0.800	3.86 ± 0.260
4	2.00	10.00	50.00	215.65 ± 0.567	224.16 ± 0.520	83.34 ± 0.521	132.31 ± 0.783	140.82 ± 0.989	5.62 ± 0.341
5	3.00	5.00	60.00	195.73 ± 0.392	216.63 ± 0.396	75.36 ± 0.360	120.37 ± 0.046	141.27 ± 0.667	6.23 ± 0.090
6	4.00	10.00	70.00	212.35 ± 0.448	257.37 ± 0.367	79.87 ± 0.306	132.48 ± 0.450	177.50 ± 0.488	5.13 ± 0.026
7	3.00	15.00	60.00	254.22 ± 0.389	296.18 ± 0.584	88.63 ± 0.462	165.59 ± 0.615	207.55 ± 0.269	5.35 ± 0.046
8	1.00	15.00	60.00	268.92 ± 0.226	211.37 ± 0.471	95.28 ± 0.457	173.64 ± 0.416	116.09 ± 0.918	4.91 ± 0.278
9	3.00	15.00	40.00	218.55 ± 0.524	231.41 ± 0.426	95.30 ± 0.517	123.25 ± 0.812	136.11 ± 0.113	6.13 ± 0.050
10	2.00	10.00	70.00	241.56 ± 0.456	255.45 ± 0.585	80.23 ± 0.376	161.33 ± 0.197	175.22 ± 0.676	5.57 ± 0.035
11	3.00	15.00	60.00	255.92 ± 0.480	297.32 ± 0.469	88.26 ± 0.480	167.66 ± 0.480	209.06 ± 0.667	5.26 ± 0.044
12	5.00	15.00	60.00	192.46 ± 0.509	260.62 ± 0.487	77.48 ± 0.444	114.98 ± 0.842	183.14 ± 0.914	6.04 ± 0.040
13	4.00	20.00	70.00	211.66 ± 0.455	278.25 ± 0.301	85.28 ± 0.535	126.38 ± 0.990	192.97 ± 0.835	4.98 ± 0.346
14	3.00	15.00	60.00	255.04 ± 0.468	297.67 ± 0.349	87.25 ± 0.410	167.79 ± 0.070	210.42 ± 0.695	5.32 ± 0.122
15	2.00	20.00	70.00	281.36 ± 0.492	262.72 ± 0.373	85.37 ± 0.495	195.99 ± 0.806	177.35 ± 0.531	4.95 ± 0.330
16	3.00	15.00	60.00	255.87 ± 0.521	297.94 ± 0.368	86.97 ± 0.350	168.90 ± 0.312	210.97 ± 0.485	5.41 ± 0.026
17	4.00	20.00	50.00	199.73±0.500	247.44 ± 0.552	85.70 ± 0.370	114.03 ± 0.870	161.74 ± 0.913	5.07 ± 0.040
18	3.00	15.00	80.00	235.65±0.449	275.67 ± 0.483	75.30 ± 0.344	160.35 ± 0.340	200.37 ± 0.504	4.88 ± 0.277
19	2.00	20.00	50.00	272.65±0.391	238.67 ± 0.386	99.37 ± 0.466	173.28 ± 0.220	139.30 ± 0.711	5.00 ± 0.373
20	3.00	15.00	60.00	253.33 ± 0.335	296.56 ± 0.456	87.67 ± 0.475	165.66 ± 0.590	208.89 ± 0.661	5.29 ± 0.070

Abbreviations: BDV, breakdown viscosity (*RVU*); DT, drying temperature (°C); FV, final viscosity (*RVU*); PRt, precooking time (min); Pt, pasting time (min); PV, peak viscosity (*RVU*); SBV, setback viscosity (*RVU*); ST, slice thickness (mm); TV, trough viscosity (*RVU*).

was a huge significant increase in FV value of the flour by 40.66%. At the same pretreatment conditions, there was also a decrease of FV value by 12.34% as slice thickness increased from 3 to 5 mm. An increase in precooking time from 5 to 15 min at a slice thickness of 3 mm and a drying temperature of 60°C significantly increased the FV value by 37.25%. Increasing the precooking time from 15 to 25 min at the same pretreatment conditions, however, decreased the FV value by 4.69%. A huge significant increase in FV value of 28.48% was observed when the drying temperature was increased from 40°C to 60°C at a slice thickness of 3 mm and precooking time of 15 min. Moreover, a significant decrease of 7.28% was observed when the drying temperature was increased from 60°C to 80°C at the same pretreatment conditions.

3.1.3 | Effect of Processing Factors on the TV

TV measures the viscosity at which the swelled flour starch granules are disrupted upon shearing and heating (Shafie et al. 2016). The highest TV of 99.37 *RVU* was obtained when WFSPs were sliced at 2 mm thickness, precooked for 20 min, and dried at a temperature of 50°C; however, the lowest TV of 75.30 *RVU* was obtained at a slice thickness of 3 mm, precooked for 15 min, and dried at a temperature of 80°C. As slice thickness increased from 1 to 3 mm at precooking time 15 min and drying temperature of 60°C, there was a decrease in TV of the flour by 7.83%. At the same pretreatment conditions, there was also a significant decrease of TV by 11.78% as slice thickness increased from 3 to 5 mm. Increase in precooking time from 5 to 15 min at a slice thickness of 3 mm and a drying temperature of 60°C significantly increased the TV by 16.54%. Increasing the precooking time from 15 to 25 min at the same pretreatment conditions also increased the TV by 5.69%. A decrease in TV by 7.85% was observed when the drying temperature was increased from 40°C to 60°C at slice thickness of 3 mm and a precooking time of 15 min. Moreover, a significant decrease of 14.26% was observed when the drying temperature was increased from 60°C to 80°C at the same pretreatment conditions.

3.1.4 | Effect of Processing Factors on the BDV

The BDV expresses the paste stability of flour and measures the ability of starch to withstand breakdown during cooling. It is an important parameter that reflects the stability of starch granules during heating and paste consistency (Patindol et al. 2005). The highest BDV of 195.99 *RVU* was obtained when WFSPs were sliced at 2 mm thickness, precooked for 20 min, and dried at a temperature of 70°C; however, the lowest BDV of 114.03 *RVU* was obtained at a slice thickness of 4 mm, precooked for 20 min, and dried at a temperature of 50°C. As slice thickness increased from 1 to 3 mm at precooking time 15 min and drying temperature of 60°C, there was a decrease in BDV of the flour by 3.86%. At the same pretreatment conditions, there was also a significant

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decrease of BDV by 31.12% as slice thickness increased from 3 to 5 mm. An increase in precooking time from 5 to 15 min at a slice thickness of 3 mm and a drying temperature of 60°C significantly increased the BDV by 27.90%. An increase in precooking time from 15 to 25 min at the same pretreatment conditions also increased the BDV by 9.81%. An increase in BDV by 26.17% was observed when the drying temperature was increased from 40°C to 60°C at a slice thickness of 3 mm and a precooking time of 15 min. Moreover, a decrease of 3.95% was observed when the drying temperature was increased from 60°C to 80°C at the same pretreatment conditions.

3.1.5 | Effect of Processing Factors on the SBV

SBV reflects the capability of starchy foods to form viscous paste after cooking and cooling. It shows the recovery of the viscosity of starch/flour during cooling of the heated starch suspension and corresponds to the retrogradation and reordering of starch molecules (Ragaee and Abdel-Aal 2006). Setback measures the re-association of starch and is associated with cohesiveness. The highest SBV of 210.97 RVU was obtained when WFSPs were sliced at 3 mm thickness, precooked for 15 min, and dried at a temperature of 60°C; however, the lowest SBV of 116.09 RVU was obtained at a slice thickness of 1 mm, precooked for 15 min, and dried at a temperature of 60°C. As slice thickness increased from 1 to 3 mm at precooking time 15 min and drying temperature of 60°C, there was a huge significant increase in SBV of the flour by 80.46%. At the same pretreatment conditions, there was also a decrease of SBV by 12.58% as slice thickness increased from 3 to 5 mm. An increase in precooking time from 5 to 15 min at a slice thickness of 3 mm and a drying temperature of 60°C significantly increased the SBV by 32.57%. Increasing the precooking time from 15 to 25 min at the same pretreatment conditions also decreased the SBV by 33.60%. An increase in SBV by 35.03% was observed when the drying temperature was increased from 40°C to 60°C at a slice thickness of 3 mm and a precooking time of 15 min. Moreover, a decrease of 4.36% was observed when the drying temperature was increased from 60°C to 80°C at the same pretreatment conditions.

3.1.6 | Effect of Processing Factors on the Pt

Pt indicates the minimum amount of time needed to cook the flour (Anberbir et al. 2024). The highest Pt of 6.44 min was obtained when WFSPs were sliced at 4 mm thickness, precooked for 10 min, and dried at a temperature of 50°C; however, the lowest Pt of 3.86 min was obtained at a slice thickness of 3 mm, precooked for 25 min, and dried at a temperature of 60°C. As slice thickness increased from 1 to 3 mm at precooking time 15 min and drying temperature of 60°C, there was an increase in Pt of the flour by 8.72%. At the same pretreatment conditions, there was also a significant increase of Pt by 13.14% as slice thickness increased from 3 to 5 mm. An increase in precooking time from 5 to 15 min at a slice thickness of 3 mm and a drying temperature of 60°C decreased the Pt by 14.31%. An increase in precooking time from 15 to 25 min at the same pretreatment conditions also significantly decreased the Pt by 27.69%. A decrease in Pt by 12.91% was observed when the drying temperature was increased from 40°C to 60°C at a slice thickness of 3 mm and a precooking time of 15 min. Moreover, a decrease of 8.59% was observed when the drying temperature was increased from 60°C to 80°C at the same pretreatment conditions.

3.2 | Interactive Effect of Processing Conditions on the Pasting Properties of the Poundo Flour

The interactive effect of the processing factors on the PV of the poundo flour is shown in Figure 2. Figure 2a shows that a high PV value of the sample was obtained at higher precooking time and lower slice thickness. It was observed that an increase in slice thickness tends to decrease the PV value of the samples, whereas increase in precooking time increased the PV value of the samples, which may be due to the absorption of more moisture with increased time during precooking. The highest PV values were obtained at a precooking time of ~21 min and a slice thickness of ~2–3 mm. Longer precooking times have been reported to generally lead to higher PV due to more extensive gelatinization and breakdown of starch granules (Balet et al. 2019; Joshi et al. 2023). Figure 2b shows that high PV value of the sample was obtained at higher drying temperature and lower slice thickness. The highest PV values were obtained at a slice thickness of ~2–3 mm and a drying temperature of ~40°C–60°C. This conforms to an earlier study by Vidhyalakshmi and Meera (2023), which reported that thinner slices allow for better gelatinization, resulting in higher PV compared to thicker slices. The study of Timm et al. (2020) reported that increasing the drying air temperature of white corn flour from 70°C to 90°C resulted in a reduction in the PV irrespective of the drying technique adopted. According to Anderson and Guraya (2006), decrease in PV may be observed due to thermal deterioration of amylopectin and amylose during drying with heated air, which worsens as the drying air temperature increases. An increase in the PV value of samples was observed as the precooking time and drying temperature increased (Figure 2c). This trend was in consonance with the study of Hong et al. (2023), which reported that PV increased with the increase in processing temperature and time. However, beyond the optimum, PV decreased with both increasing precooking time and increasing drying temperature. Moreover, the findings of Malumba et al. (2009) reported that increase in the drying air temperature from 54°C to 130°C reduced the PV of corn starch granules. The variation in the PV values suggests that there may be differences in the behavior of the various flour categories during thermal application (Ragaee and Abdel-Aal 2006). It was observed from Figure 2c that PV was highest at intermediate values of drying temperature and precooking time, as the highest PV was obtained at a drying temperature of ~60°C and a precooking time of ~13 min.

The interactive effect of the processing factors on the FV of the poundo flour is shown in Figure 3. Figure 3a shows that as both the precooking time and slice thickness increase, the FV generally increases, reaching a peak at the optimum (slice thickness of ~3–4 mm and precooking time of ~9–13 min), and then potentially decreasing slightly at the extremes. The increment in the FV indicates formation of a firm gel after cooking and cooling, rather than a viscous paste (Jimoh et al. 2009). This was in consonance with the study of Iwe et al. (2016), which reported that the difference in the FV of composite flour is attributed to the basic

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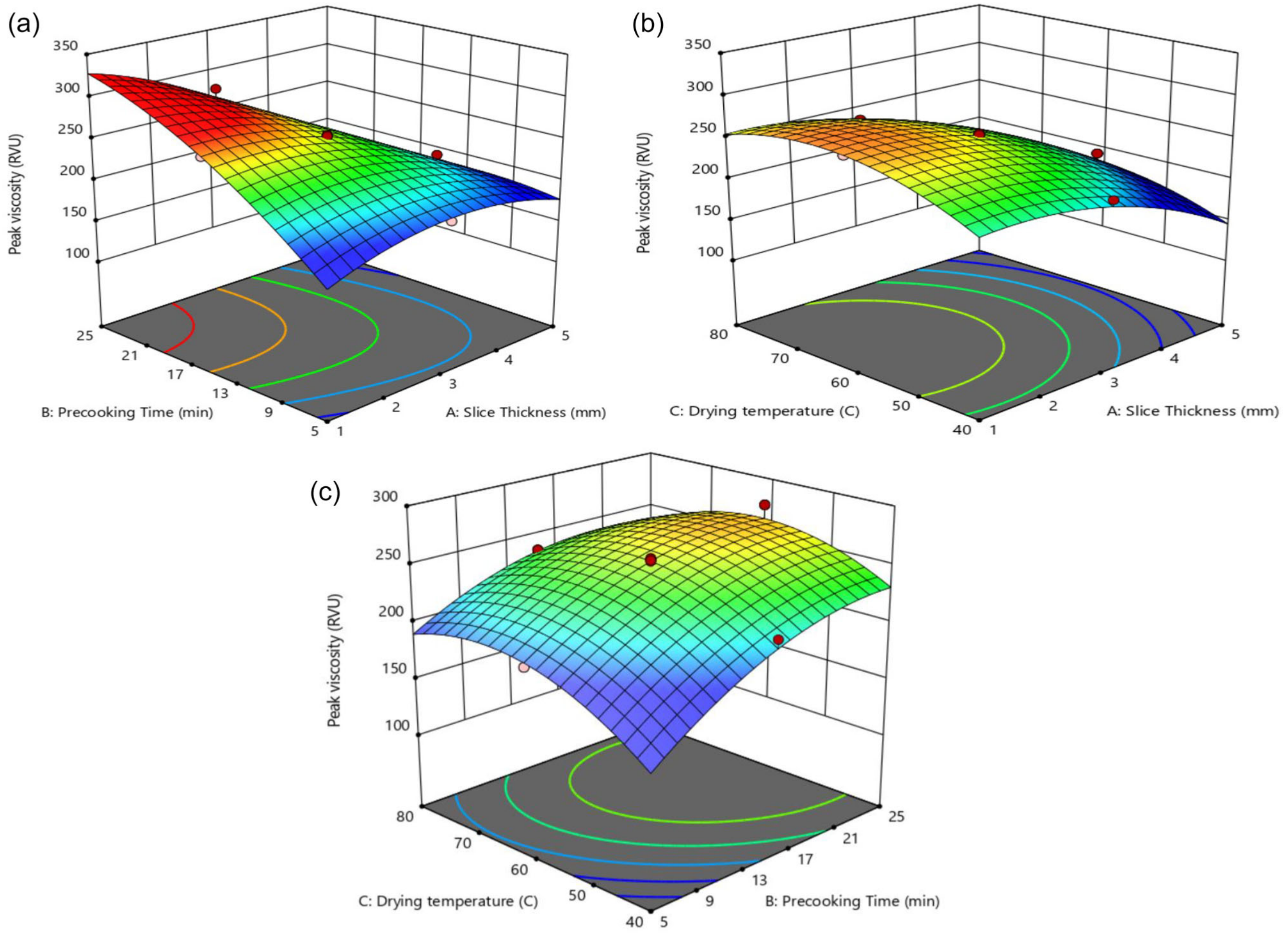

FIGURE 2 | (a) Response surface plot of the interactive effects of slice thickness and precooking time on the peak viscosity of the poundo flour; (b) response surface plot of the interactive effects of slice thickness and drying temperature on the peak viscosity of the poundo flour; (c) response surface plot of the interactive effects of precooking time and drying temperature on the peak viscosity of the poundo flour.

kinetic effects of cooling in viscosity and the re-association of starch molecules in the flour samples. It should be noted that beyond the optimum value, increase in precooking time has an adverse effect on FV. Figure 3b shows that the FV increases with both slice thickness and drying temperature, reaching a peak at the optimum and then decreasing slightly at the extremes. This agrees with the findings of Rosell et al. (2011), which reported that increasing the particle size (slice thickness) of wheat flour led to higher FV of dough, likely due to more intact starch granules that could swell and contribute to viscosity. Particle size has been reported to be a significant factor affecting FV (He et al. 2024).

Optimal FV was obtained at slice thickness of ~3–4 mm and drying temperature of ~60°C–65°C. Figure 3c shows that the FV increases as both precooking time and drying temperature increase. This trend was consistent with the earlier study of Hong et al. (2023), which observed that FV increased with the increase in processing temperature and time. Increasing precooking time leads to increased water absorption and swelling of starch granules, which in turn increases the FV of the flour paste (Cozzolino et al. 2012). Similarly, research on the pasting and viscoelastic properties of various flours demonstrated that extended cooking times enhance the gelation process, thus increasing the FV (Abd Karim et al. 2000). Nevertheless, it was observed that beyond the optimum values (precooking time of ~13–17 min and a drying temperature of ~60°C–65°C), there is a decline. Timm et al. (2020) reported that increasing the drying air temperature of white corn flour from 70°C to 90°C resulted in a decrease in the FV irrespective of the drying technique adopted.

The interactive effect of the processing factors on the TV of the poundo flour is shown in Figure 4. The highest TV was observed at a precooking time of ~25 min and a slice thickness of ~1 mm (Figure 4a). This implies that the thinnest slices and the longest precooking time result in the highest TV, which was consistent with the findings of Ekwu et al. (2014), which reported highest TV for peeled, sliced, and dried samples during the processing of abacha slices. This suggests that the granules would be less prone to rupture during pasting, and its cooked paste would be more stable (Adebowale et al. 2008). In Figure 4b, the highest TV was observed at a slice thickness of between ~3 and 4 mm and the drying temperature of ~50°C to 60°C. At lower slice thickness values (~1–2 mm), TV tends to be lower, and as the slice thickness increases (~2–4 mm), TV increases, reaching an optimal value at ~4 mm. Beyond 4 mm, however, it begins to decline slightly. Similarly, at lower drying temperatures (~40°C–50°C), TV is lower, but it increases as drying temperature increases (~50°C–60°C), reaching an optimal value at ~60°C, beyond which it starts

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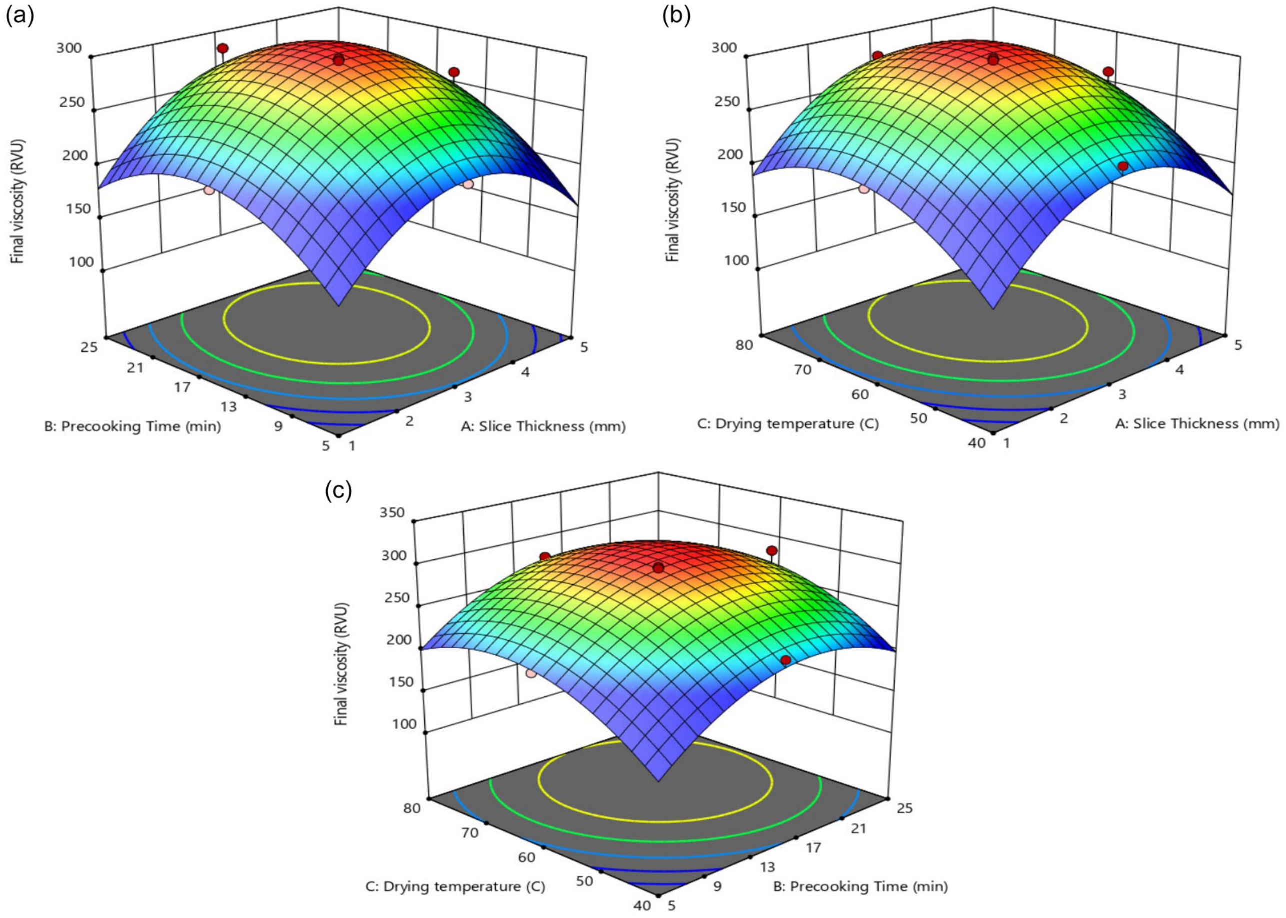

FIGURE 3 | (a) Response surface plot of the interactive effects of slice thickness and precooking time on the final viscosity of the poundo flour; (b) response surface plot of the interactive effects of slice thickness and drying temperature on the final viscosity of the poundo flour; (c) response surface plot of the interactive effects of precooking time and drying temperature on the final viscosity of the poundo flour.

to decline. The TV increases as both the drying temperature and precooking time increase, reaching the optimum at the highest precooking times and drying temperatures, as shown in Figure 4c. Ensuring that the flour is dried at a higher temperature helps to reduce its moisture content and alter the starch structure, leading to higher TV upon cooling; however, extending the precooking time allows for more thorough gelatinization of the starch, which enhances the TV during the cooling phase. This trend supports the findings of Hong et al. (2023), which reported that TV increased with increase in processing temperature and time.

The interactive effect of the processing factors on the BDV of the poundo flour is shown in Figure 5. As the slice thickness increases, it was observed that the BDV decreases (Figure 5a). This implies that thicker slices result in lower BDV, possibly due to reduced heat penetration or slower gelatinization of starch within thicker slices. Furthermore, as the precooking time increases, the BDV decreases as well. Longer cooking time may lead to more breakdown of starch structures, reducing the BDV. The combined increase in slice thickness and precooking time amplifies the decrease in BDV, suggesting a synergistic effect where the interaction between these two factors accelerates the breakdown process. Optimal BDV was obtained at a slice thickness of ~1 mm and a precooking time of ~10 min. Although some BDV is essential for proper cooking, excessively high BDV can diminish flour's ability to handle heat and shear stress, leading to compromised texture and quality in the final product (Adebowale et al. 2008). In Figure 5b, the BDV reaches its peak at a slice thickness of ~1 mm and a drying temperature of ~40°C. As slice thickness increases from 1 to 5 mm, the BDV decreases. This indicates that thicker slices result in lower BDV, likely due to slower heat penetration or structural effects during processing. As the drying temperature increases (from 40°C to 80°C), the BDV decreases. Higher drying temperatures may cause structural or chemical changes in the material, leading to reduced BDV. Figure 5c shows that the highest BDV occurs when the precooking time is short (~5 min) and drying temperature is low (~40°C). This observation was in line with an early study by Timm et al. (2020), which observed a decreasing trend in BDV as the drying air temperature of white corn flour increased. Long precooking times typically allow for more complete gelatinization of the starch granules in the flour. More extensive gelatinization can lead to a higher initial viscosity. After gelatinization, as the starch is subjected to shear and further heating, the viscosity tends to decrease, referred to as BDV. When both precooking time and drying temperature are increased, the combined effects on starch gelatinization, structural changes, and moisture content can lead to a more significant breakdown in viscosity during the heating process. This is because more thoroughly gelatinized

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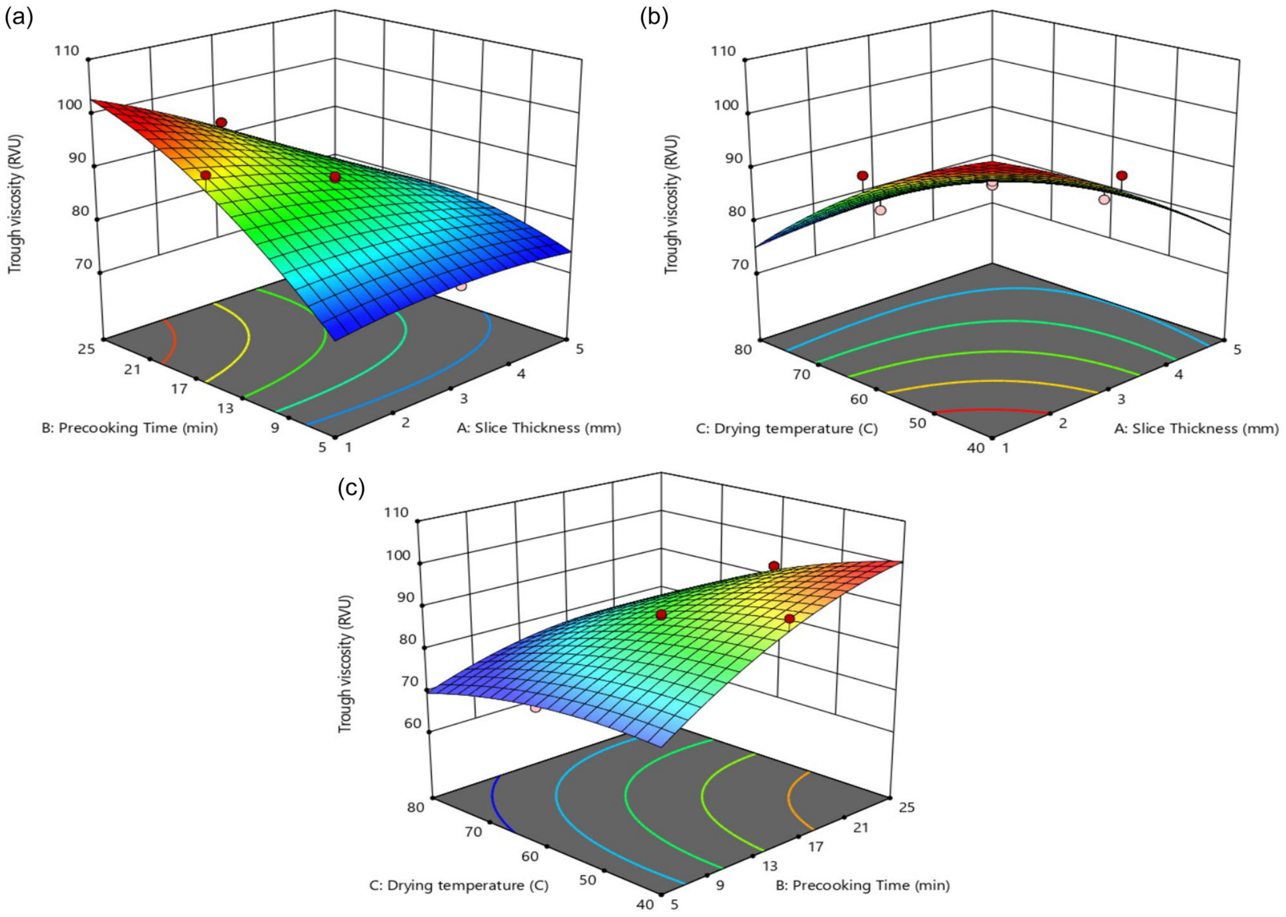

FIGURE 4 | (a) Response surface plot of the interactive effects of slice thickness and precooking time on the trough viscosity of the poundo flour; (b) response surface plot of the interactive effects of slice thickness and drying temperature on the trough viscosity of the poundo flour; (c) response surface plot of the interactive effects of precooking time and drying temperature on the trough viscosity of the poundo flour.

and structurally altered starches are more prone to shear-induced breakdown. Starches with low paste stability or breakdown have very weak cross-linking within the granules.

The interactive effect of the processing factors on the SBV of the poundo flour is shown in Figure 6. The highest SBV was observed at intermediate values of both precooking time and slice thickness (Figure 6a). SBV increases at smaller thicknesses (∼1–3 mm) but eventually declines slightly at larger thicknesses. As precooking time increases, SBV also follows a similar trend as it initially increases and then starts to decrease beyond a certain point (∼13–17 min). For this interaction, the highest SBV was obtained at ∼3 mm slice thickness and ∼13–17 min of precooking time. Furthermore, short precooking time (∼5 min) and very small slice thickness (∼1 mm) or very large slice thickness (∼5 mm) resulted in decreased SBV. A high SBV value is associated with a cohesive paste and a high rate of starch retrogradation and synergies, whereas a low SBV value is characterized by the reverse (Jimoh et al. 2009; Kaur and Singh 2005; Ragaee and Abdel-Aal 2006). In Figure 6b, it was observed that SBV increases with thickness (∼1–3 mm) but slightly declines at higher thicknesses (∼4–5 mm). Moreover, SBV initially increases and reaches a peak at moderate drying temperatures (∼50°C–60°C). Beyond this range, the viscosity decreases as the temperature exceeds ∼70°C. This agreed with the study of Timm et al. (2020), which observed that increasing the drying air temperature of white corn flour from 70°C to 90°C resulted in a decrease in the SBV irrespective of the drying technique adopted. According to Anderson and Guraya (2006), decrease in SBV may be observed due to thermal deterioration of amylopectin and amylose during drying with heated air, and increasing the drying air temperature further causes more adverse effects. It was also observed from the plot that lower drying temperatures (< 50°C) result in lower SBV, regardless of the slice thickness. According to earlier reports, a high SBV improves moldability, which is beneficial for textural quality in instant poundo yam dough or pounded yam (Olagunju-Yusuf et al. 2019; Otegbayo et al. 2006). In Figure 6c, SBV is low at shorter precooking times (∼0–5 min). However, as the precooking time increases to moderate levels (∼13–15 min), SBV reaches a maximum. Beyond ∼20 min of precooking, it decreases again. Similarly, at low drying temperatures (∼40°C–50°C), SBV is relatively low. As the drying temperature increases to moderate levels (∼55°C–60°C), it reaches its peak, and at high drying temperatures (∼70°C–80°C), it decreases again. It was observed that low or very high drying temperatures combined with very short or very long precooking times lead to low SBV. The SBV of starch has been reported to be inversely correlated with the retrogradation of the flour paste during cooling and the staling rate of products made from the flour (Dasa and Binh 2020).

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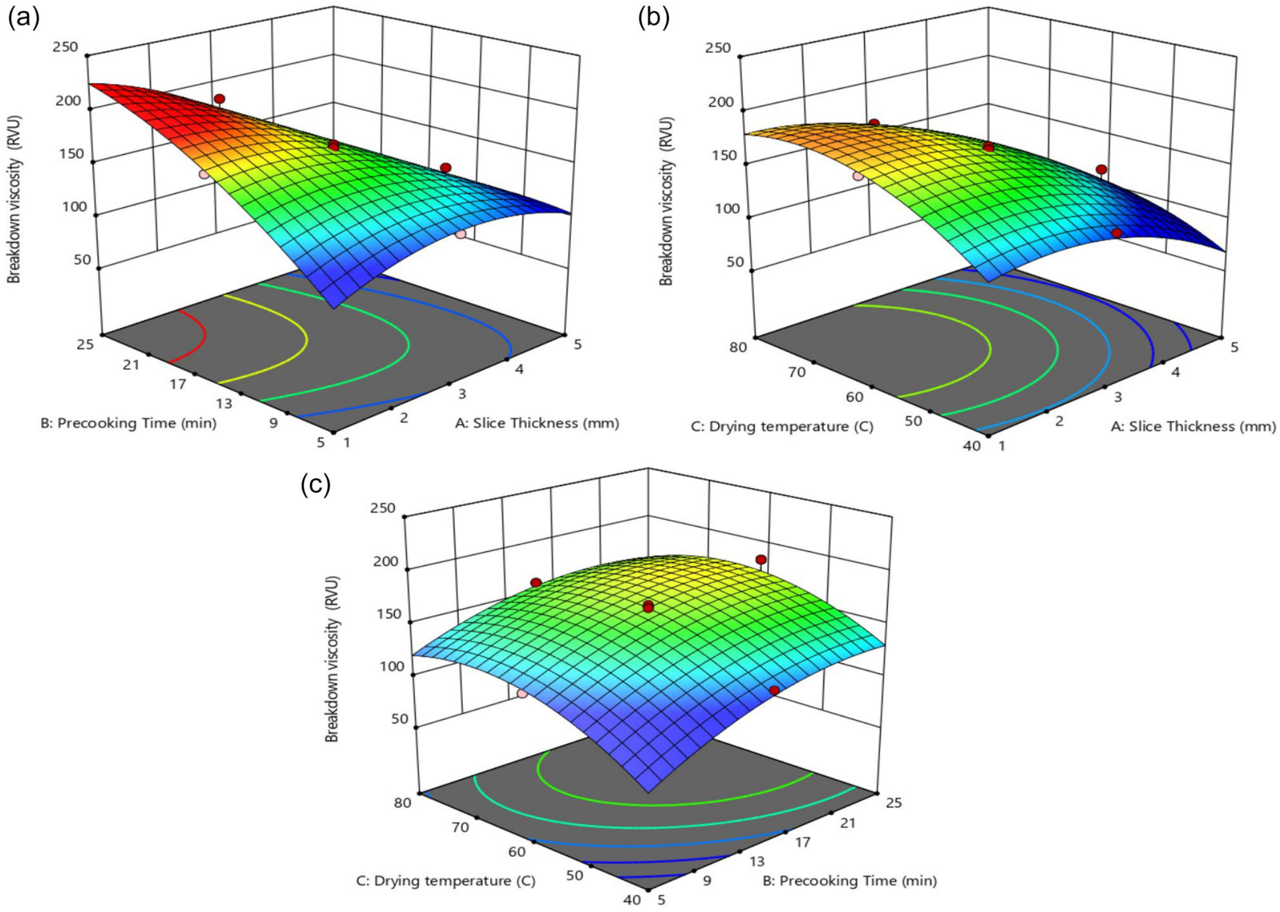

FIGURE 5 | (a) Response surface plot of the interactive effects of slice thickness and precooking time on the breakdown viscosity of the poundo flour; (b) response surface plot of the interactive effects of slice thickness and drying temperature on the breakdown viscosity of the poundo flour; (c) response surface plot of the interactive effects of precooking time and drying temperature on the breakdown viscosity of the poundo flour.

The interactive effect of the processing factors on the Pt of the poundo flour is shown in Figure 7. In Figure 7a, increasing the precooking time and slice thickness generally increases the Pt; thus, in order to reduce the Pt, thinner slices and lower precooking times are highly desirable. Thicker slices might retain more moisture and take longer to reach the pasting stage, thereby increasing the Pt. In addition, longer precooking times might allow more thorough gelatinization of starch, leading to a higher Pt. However, in extreme cases, it could cause excessive gelatinization and breakdown of starch granules, which lowers the structural integrity. The lowest Pt was observed when the slice thickness is ~3 mm and the precooking time is ~5 min. Away from this optimal point, it was observed that the Pt increased significantly. For instance, higher precooking times above 15 min lead to much longer Pt, even with optimal slice thickness. Similarly, thicker slice thickness above 4 mm also increases Pt, even with an optimal precooking time. Excessively high Pts can indicate damaged or aged starch granules, which can negatively impact final product quality. In Figure 7b, as the drying temperature increases, the Pt increases, indicating that higher drying temperatures lead to longer Pt. High temperatures facilitate more efficient moisture removal during drying, leading to a more optimal texture and structure that results in longer Pt. At excessively high temperatures (above 70°C), the material may become overly dried, leading to structural changes that negatively impact the pasting properties. Controlling the slice thickness and drying temperature is crucial for optimum Pt. Thicker slices have a higher surface area-to-volume ratio, which can slow down the drying process (El-Mesery et al. 2023). This more gradual drying allows the material to better retain its optimal structural and textural characteristics, resulting in longer Pt. However, at lower drying temperatures, drying might be extremely slow and consequently have an adverse effect on the material. Slices thicker than 3 mm may take too long to dry, leading to undesirable changes in the material properties. Conversely, very thin slices may dry too quickly at higher temperatures, causing the material to become brittle or altered, leading to shorter Pt but having an adverse effect on the material. In Figure 7c, the Pt increases with increasing precooking time. Long precooking times (~20–25 min) may lead to partial gelatinization of starch, which stabilizes the structure and increases the time required to reach full pasting upon further heating, whereas overextended precooking times could cause excessive gelatinization and breakdown of starch granules, which lowers the structural integrity. It was also observed from the plot that the Pt increases as drying temperature increases up to ~70°C. Higher drying temperatures likely induce more extensive structural changes in the starch granules, making them more resistant to swelling and gelatinization, thus requiring more time to reach the pasting point. However, after reaching a peak at ~70°C, further increasing the drying temperature results

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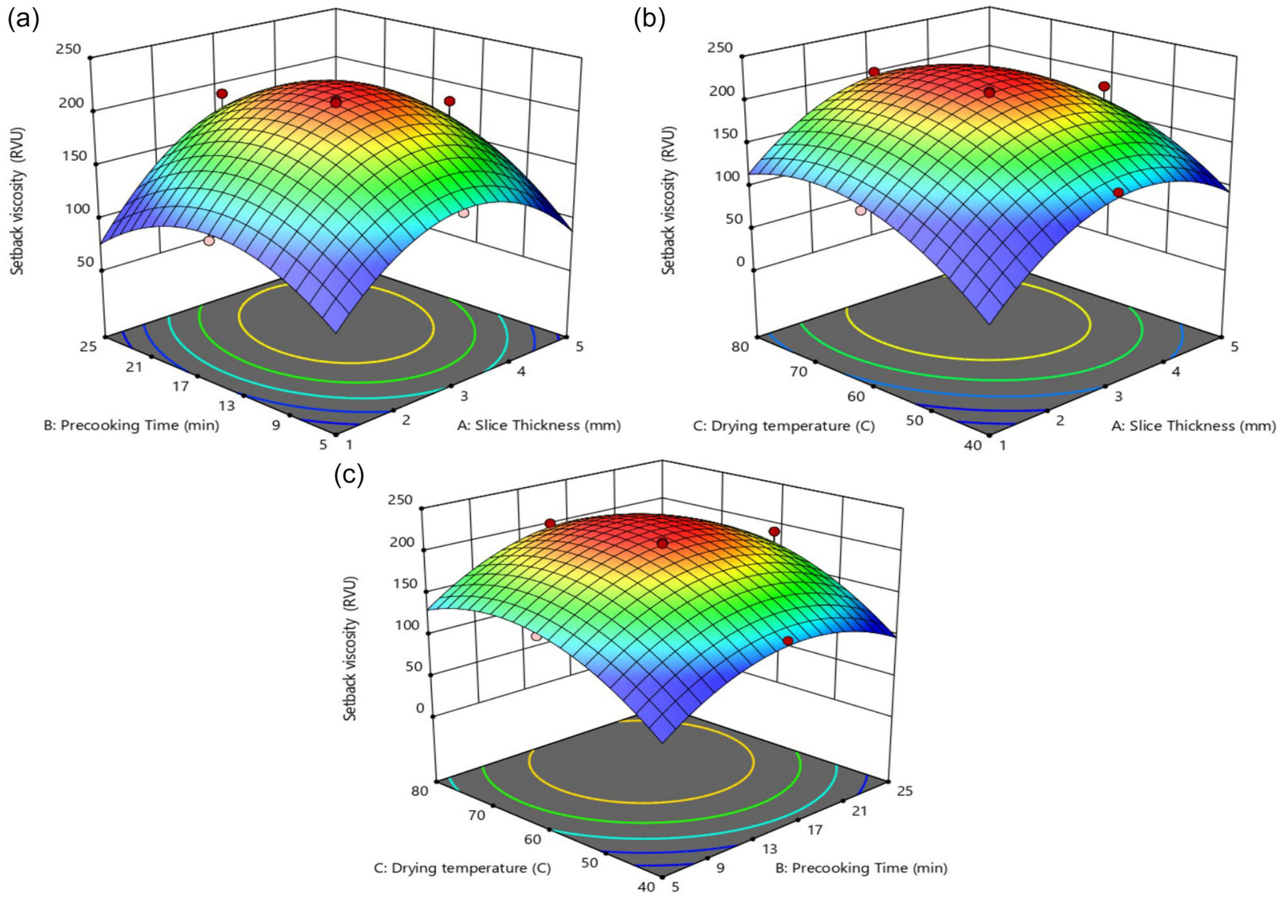

FIGURE 6 | (a) Response surface plot of the interactive effects of slice thickness and precooking time on the setback viscosity of the poundo flour; (b) response surface plot of the interactive effects of slice thickness and drying temperature on the setback viscosity of the poundo flour; (c) response surface plot of the interactive effects of precooking time and drying temperature on the setback viscosity of the poundo flour.

in a decrease in Pt. Pt has been significantly positively correlated with temperature, implying that starch with high gelatinization temperatures needs longer time to get pasting and gelatinization (Tappiban et al. 2020). Excessive drying temperatures may lead to degradation of the starch structure, reducing the viscosity and Pt. This degradation can cause the starch granules to break down more easily, leading to a quicker Pt. One thing worthy of note is that flours with low Pts (~5–10 min) are preferred for products where a soft, tender crumb is desirable, like poundo yam dough, cakes, cookies, quick breads, and poundo, whereas flours with higher Pts (~15–25 min) are better suited for yeast-leavened breads, where a firmer, chewier texture is preferred (Adebowale et al. 2011; Anberbir et al. 2024).

3.3 | Optimization and Model Validation of the Pasting Properties of the Poundo Flour

The pasting properties were optimized by fitting the various obtained results to the linear, two-factorial interaction, quadratic, and cubic models. On the basis of the results obtained in this study, the quadratic model was found to be the most appropriate model for predicting the PV, FV, BDV, and SBV, whereas the linear model was found to be the most appropriate model for predicting the TV and Pt. These models were suggested by the Design Expert software considering the criteria of higher coefficient of determination (R^2) and lower standard deviation (see Appendix A). The ANOVA tables are presented in Appendix B. p values less than 0.05 indicate model terms are significant, and in this study, $A, B, C, AB, A^2, B^2, C^2$ are significant model terms for PV; A, B, C, A^2, B^2, C^2 are significant model terms for FV; A, B, C are significant model terms for TV; A, B, C, AB, A^2, B^2, C^2 are significant model terms for BDV; A, B, C, A^2, B^2, C^2 are significant model terms for SBV; and A, B, C are significant model terms for Pt. Note that A, B, and C represent slice thickness, precooking time, and drying temperature, respectively.

The final model equations in terms of coded values for the various pasting properties are given in the following equations:

$$PV = 253.32 - 21.38A + 16.14B + 5.92C - 6.74A^2 - 5.43B^2 - 7.64C^2 - 12.02AB - 1.09AC - 2.41BC \tag{1}$$

$$FV = 1\ 295.48 + 8.08A + 12.18B + 12.71C - 16.25A^2 - 12.75B^2 - 11.87C^2 + 2.23AB + 0.52AC - 0.64BC \tag{2}$$

$$TV = 86.02 - 3.15A + 4.03B - 3.77C \tag{3}$$

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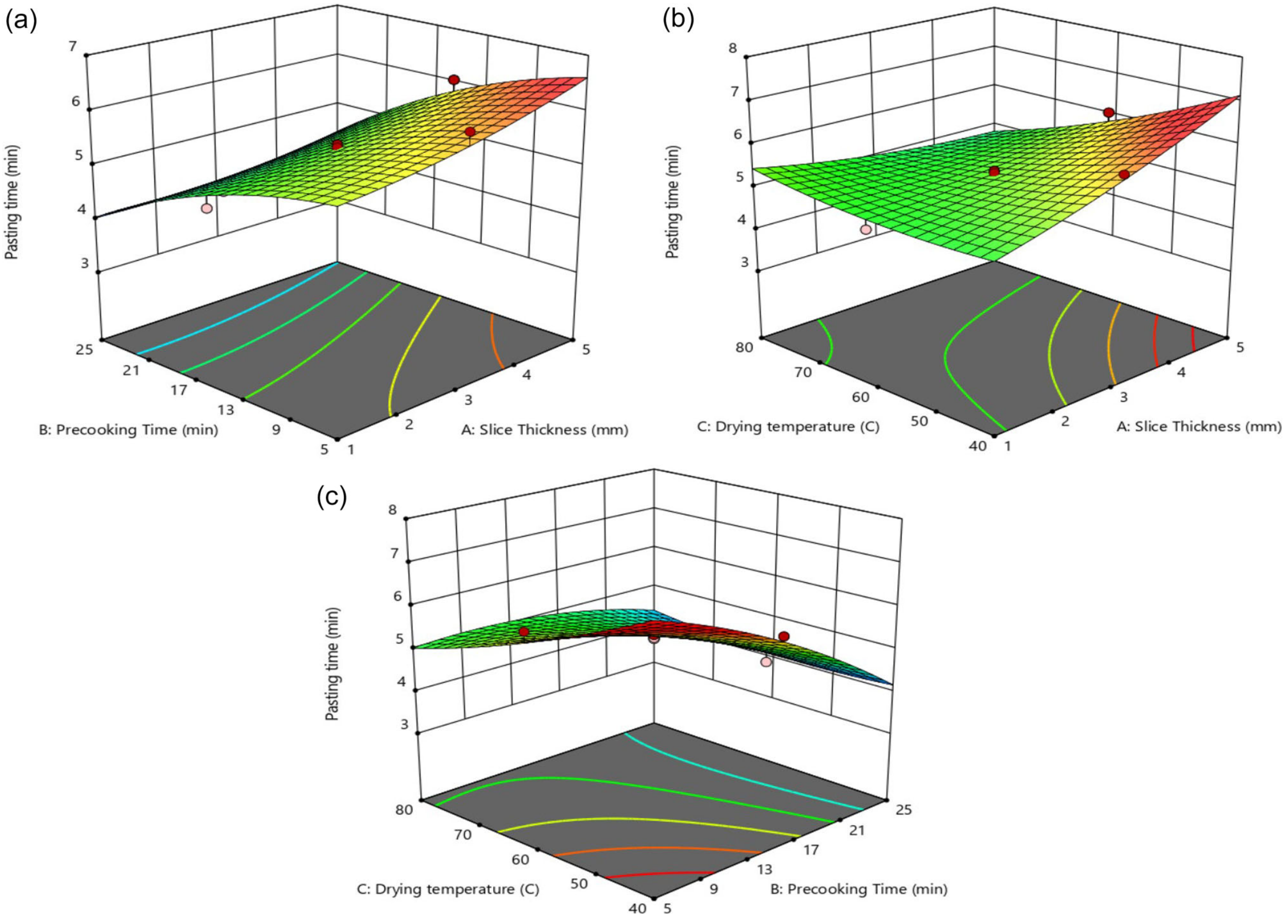

FIGURE 7 | (a) Response surface plot of the interactive effects of slice thickness and precooking time on the pasting time of the poundo flour. (b) Response surface plot of the interactive effects of slice thickness and drying temperature on the pasting time of the poundo flour; (c) response surface plot of the interactive effects of precooking time and drying temperature on the pasting time of the poundo flour.

$$BDV = 165.61 - 18.23A + 12.11B + 9.69C - 6.32A^2 - 4.44B^2 - 6.95C^2 - 10.42AB - 2.82AC - 1.35BC \quad (4)$$

$$SBV = 207.78 + 11.22A + 8.15B + 16.48C - 15.83A^2 - 11.76B^2 - 11.17C^2 + 3.83AB - 1.21AC + 0.42BC \quad (5)$$

$$Pt = 5.34 + 0.17A - 0.47B - 0.25C \quad (6)$$

High coefficients of determination of 0.96, 0.94, 0.80, 0.95, 0.93, and 0.78 were obtained for the PV, FV, TV, BDV, SBV, and Pt, respectively, and these exhibited good correlations between the independent variables. According to these values, 96%, 94%, 80%, 95%, 93%, and 78% of the overall variability in the respective corresponding responses can be explained by the response model. Adequate precision evaluates the signal-to-noise ratio, with a ratio above 4 being considered desirable. The ratios of 17.77, 10.86, 15.31, 16.73, 11.22, and 14.27 for PV, FV, TV, BDV, SBV, and Pt, respectively, indicate a sufficient signal (see Appendix A). Therefore, the selected models are suitable for navigating the design space.

In the range of 1–5 mm slice thickness, 5–25 min precooking time, and 40°C–80°C drying temperature, where the goal for the optimization was to maximize the viscosities and minimize the Pt, predicted optimum PV, FV, TV, BDV, SBV, and Pt of 281.36 RVU, 283.81 RVU, 90.90 RVU, 190.71 RVU, 193.16 RVU, and 4.54 min, respectively, were obtained at 2.51 mm slice thickness, 21.38 min precooking time, and 64.79°C drying temperature with a desirability of 0.82 (Figure 8). This was experimentally validated to give corresponding values of 282.36 RVU, 282.21 RVU, 91.04 RVU, 190.22 RVU, 193.59 RVU, and 4.46 min, respectively. Percentage errors of 0.354, 0.567, 0.154, 0.258, 0.222, and 1.794 were obtained for PV, FV, TV, BDV, SBV, and Pt, in that order. The low variation between the experimental and predicted optimal values indicates that, within the range of the variables considered in this study, the developed models obtained can adequately predict the pasting properties of poundo flour derived from precooked sweet potato tubers.

4 | Conclusions

This study highlights the significant impact of processing variables, such as slice thickness, precooking time, and drying temperature, on the pasting properties of poundo flour made from precooked sweet potato tubers. It was established that these

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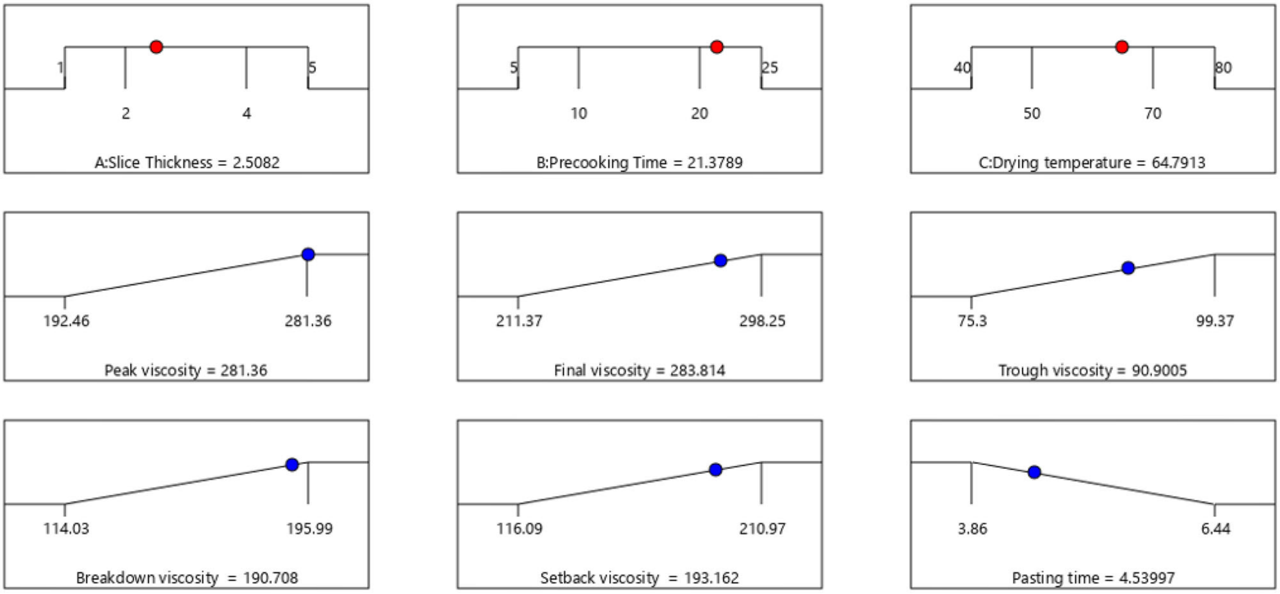

FIGURE 8 | Optimization of the pasting properties of the poundo flour.

factors greatly influence key pasting characteristics, including PV, TV, BDV, FV, SBV, and Pt. These results emphasize the importance of optimizing processing conditions to enhance the textural quality and functional properties of the final flour product. The minimal difference between the experimental and predicted optimal values demonstrates the accuracy and reliability of the developed models, confirming their effectiveness in predicting pasting properties within the tested range of variables. This reliability underscores their practical value in optimizing the production process for poundo flour. This research makes a valuable contribution to food science by providing actionable insights for optimizing flour formulations designed for specific applications. The findings highlight opportunities to improve product consistency, stability, and texture, paving the way for high-quality outcomes. Furthermore, the study offers a solid basis for the food industry to innovate in the development of premium sweet potato–based products while ensuring efficient and scalable production methods. Future research could further explore the relationship between processing parameters and functional properties, broadening the scope of applications across various flour products.

Author Contributions

Olayemi Olubunmi Ojoawo: conceptualization, methodology, investigation, validation, software, data curation, writing–original draft, writing–review and editing, visualization, formal analysis, resources. **Bolanle Adenike Adejumo**: supervision, visualization, project administration, writing–review and editing, resources. **Samuel Tunde Olorunsogo**: supervision, visualization, project administration, resources. **Ocheme Boniface Ocheme**: visualization, validation.

Conflicts of Interest

The authors declare no conflicts of interest.

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