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Some quality properties of yellow-fleshed sweet potato flour as affected by different drying methods

Olanike Aishat Badiora*, Tunde Afolabi Morakinyo and Kehinde Adekunbi Taiwo

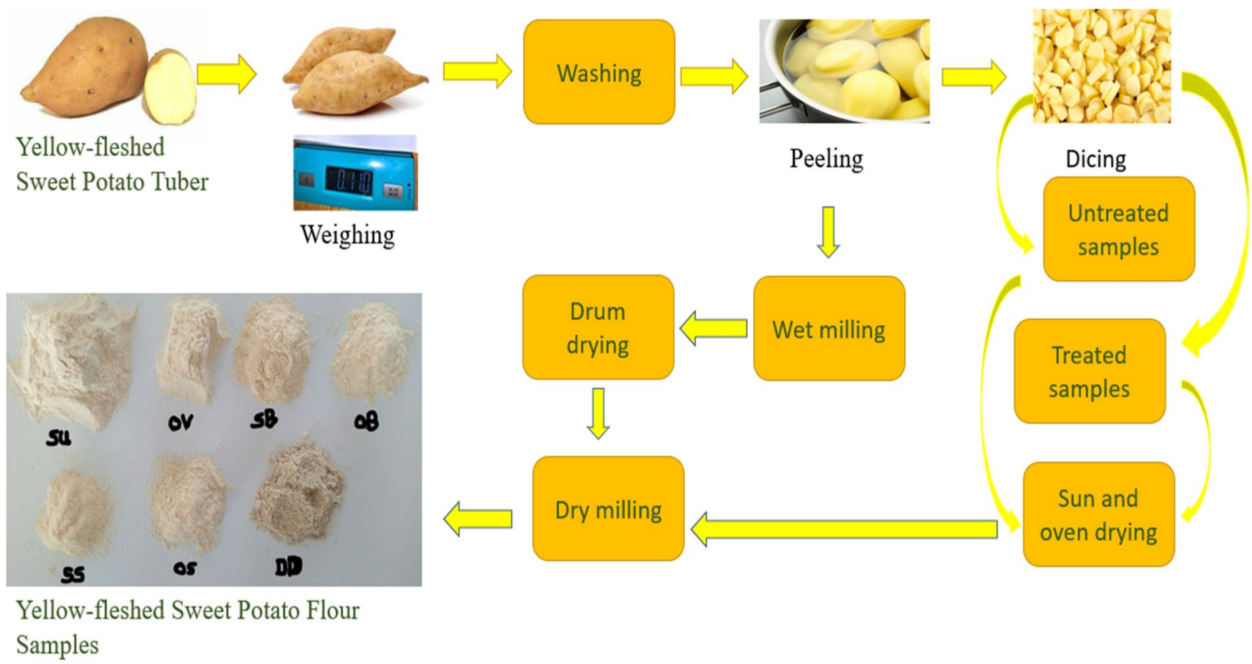
Abstract

This study compared some quality properties of yellow-fleshed sweet potato flour samples as affected by pretreatments (0.02% sulfite; blanching 85 °C for 3 min 30 s and steam blanching 100 °C for 2 min) and drying methods (oven, sun, and drum drying). The physicochemical composition, functional properties, pasting profile, and least gelation concentration of the flours were determined. Before pretreatment, the sweet potato tubers were sorted, weighed, rinsed, peeled, and diced. The smallest particle size (58 μm) was recorded for samples blanched at 85 °C followed by oven drying while drum-dried samples had the largest particle size (119.5 μm). The pH values (5.58 - 5.90) of the pretreated sun- and oven-dried samples were significantly ($p<0.05$) impacted by 0.02% sulfite. Compared to other drying methods. drum-dried samples had low bulk density (0.36 g/ml), the highest water (531%) and oil absorption capacities (168.5%,) and the least dispersibility (35%). Drum-dried samples had the highest swelling capacities at 60 – 80 °C but the values decreased at 80 – 90 °C compared to samples from other drying methods that had low swelling capacity at 60 - 70 °C but the values increased as the temperature increased from 70 – 90 °C. Results of the sample pasting profiles showed that pretreatment and drying techniques were significant on the various viscosities measured. Drum-dried samples had the lowest trough viscosity (18.13 RVU), final viscosity (24.88 RVU), setback viscosity (6.75 RVU), peak time (1.07 min), and pasting temperature (0 °C). This study concluded that the pretreatment and drying methods affected the quality properties of the yellow-fleshed sweet potato flour samples differently, consequently altering their functionality.

Keywords Flour, Functional properties, Quality properties, Untreated, Pretreated, Yellow-fleshed sweet potato flour

*Correspondence:
Olanike Aishat Badiora
afolarino84@gmail.com; badioraolanike2020@gmail.com
Full list of author information is available at the end of the article

Graphical Abstract



Introduction

Sweet potato *(Ipomoea batatas)* is a widely cultivated tuber that is one of the main sources of energy globally (Konczak-Islam et al. 2003). Based on the quantity produced, it is positioned as the seventh staple crop after maize, rice, cassava, potato, and wheat (Senevirathna et al. 2021). Generally, sweet potato contains a substantial amount of carbohydrates (20.12%) but has a low glycemic index, which could benefit diabetic patients (International Life Sciences Institute (ILSI) 2008). Sweet potato tuber contains a large amount of beta carotene (7.91 to 12.85 mg/100 g), potassium (260 mg/100 g), phosphorus (51 mg/100 g), and calcium (29 mg/100 g) (Woolfe 1992). However, the crop has a low amount of protein (1.57%) and fats (0.05%) (Woolfe 1992). Freshly harvested yellow-fleshed sweet potato tuber crops are hard to keep for a long time due to the high moisture content of up to 70% (Morakinyo & Taiwo 2016). Processing sweet potato tuber roots into flour produce a shelf-stable product (Wireko-Manu et al. 2010). The processing of the tuber into different products like chips, flour, flakes, and starch, has been suggested as means of tackling the storage and transportation of freshly harvested yellow-fleshed sweet potato tubers (Owori & Agona 2003). Different food processing techniques have been reported to influence the functional composition of dried foods (Wahab et al. 2015).

The quality of sweet potatoes flour has been reported to be affected by the type of cultivars, and unit operations, in addition to production techniques such as pre-cooking, treatment, drying techniques, peeling methods, chemical treatment subjected to and dehydrating temperatures (Olatunde et al., 2016). De Moura et al. (2015) studied the difference in physiognomies of sweet potato flour produced from different dehydrating conditions (sun, drum, and oven drying). The influence of blanching and drying temperatures on selected properties of sweet potato (*Ipomoea batatas*) flour was studied by Orhevba and Abimaje (2019). The study showed that both blanching and drying temperatures affected the bulk densities and proximate properties of sweet potato flour except for crude fiber which was not significantly different. Drum drying has the potential to enhance protein digestibility, make more amino acids present and maintain the carotenoids as pure beta-carotene than spray and freeze-drying (Arrage et al. 1992; Desobry et al. 1997). Belkacemi (2022) reported a significant reduction in the polyphenols and tannins content of unpeeled and peeled blanched sweet potato-based flours. In addition, both unpeeling and blanching increased the water absorption capacity, swelling power, water solubility, and emulsifying capacity of sweet potato flour. Dereje et al. (2020) observed a significant variation in the functional properties of sweet potato flours as influenced by the variety and some processing methods. Ruttarattanamongkol et al. (2016) reported that the drying processes significantly enhanced anthocyanin contents of sweet potato flours by 1.8 to 3.8 times while there was a significant loss of carotene. Drum drying yielded sweet potato flours with better color, higher total phenolic contents, and antioxidant activity than hot air drying. Pasting temperatures of hot air-dried orange-fleshed sweet potato flour were slightly higher than those of purple-fleshed sweet potato flour. Other scholars have worked on yellow-fleshed sweet potato flour but have focused on developing new products without identifying the most suitable processing techniques (van Hal 2000). Hence, this study is designed to compare the influence of various dehydrating techniques (sun, oven, and drum drying) on some quality properties (physicochemical, functional, pasting, and least gelation concentration) of flour produced from yellow-fleshed sweet potato tubers.

Materials and methods

Materials

Yellow-fleshed sweet potato (YFSP) tuber was procured from *Oja Tuntun* in Ile – Ife, Osun State. Other materials including laboratory equipment used in the production of YFSP flour samples were obtained in the Department of Food Science and Technology, Obafemi Awolowo University, Ile – Ife, Osun State, Nigeria.

Methods

Preparation of untreated yellow-fleshed sweet potato flour samples

Yellow-fleshed sweet potato (*Ipomoea batatas*) tubers were weighed and sorted to remove the damaged tubers. The sorted tubers were washed in a vat, manually peeled with a sweet potato peeler, and subsequently diced into smaller pieces of 1.5 mm thickness using a size reduction machine (AB Hallde Maskiner Sweden RG – Z – PAT No: 8900 dicing machine) (Jangchud et al. 2003). The diced yellow-fleshed sweet potato tubers were sun-dried (for 3 to 4 days at an average temperature of 27 ± 2 °C) and oven-dried (70 °C for 8 h using a cabinet drier) without any pretreatment as described in Table 1 (Jangchud et al., 2003; Woolfe 1992).

Preparation of pretreated samples (blanching)

Yellow-fleshed sweet potato tubers were washed, manually peeled, and diced into water containing 0.02% sulfite to deactivate enzymes that could result in a browning reaction. This was followed by blanching the diced samples in water at 85 °C for 3 min 30 s and immediately cooled before drying as described in Table 1 (Afolabi et al. 2021).

Preparation of pretreated samples (steam blanching)

The sulfited diced samples were steam blanched in a blancher. Steam was discharged into the steam blancher until the chamber temperature was above 100 °C. The samples were placed in the blanching chamber for 2 min above 100 °C before drying.

Drying of the untreated and pre-treated samples

Untreated and pre-treated samples were subjected to sun and oven drying. Sun-drying was undertaken for 3 to 4 days at an average temperature of 27 ± 2 °C. Oven drying was conducted at 70 °C for 8 h using a cabinet drier (Woolfe 1992). The temperature of 70 °C for 8 h was selected for oven-dried samples as used in the study of Jangchud et al. (2003).

Drum drying

For drum-dried samples, the yellow-fleshed sweet potato tubers (2 kg) were washed, peeled, and wet milled into a slurry using a Premier mill (No 1 A Hunt mill, R. Hunt and Co. Ltd., Earls Colne, Colchester, Essex, UK) while 500 ml of water was added to get a moisture content of 84.05%. The tubers were not pretreated before wet milling into

Table 1 Sample Preparations

Sample Code	Drying Methods	Conditions
SU	Sun-dried	untreated, 3 – 4 days at 27 ± 2 °C
OU	Oven-dried	untreated at 70 °C for 8 h
SB	Sun-dried	0.02% sulfite, blanched at 85 °C for 3 min 30 s dried for 3 – 4 days at 27 ± 2 °C
OB	Oven-dried	0.02% sulfite, blanched at 85 °C for 3 min 30 s oven-dried at 70 °C for 8 h
SS	Sun-dried	0.02% sulfite, steam blanched for 2 min sun-dried for 3 – 4 days at 27 ± 2 °C
OS	Oven-dried	0.02% sulfite, steam blanched for 2 min oven-dried at 70 °C for 8 h
DD	Drum-dried	150, 10 rpm, 100 ml (84.05%)

a slurry. The slurry was drum dried using a drum dryer (Goudshe Machine Fabriek B.V, Gouda, Holland). The drum dryer was heated using indirect heat (superheated steam generated from the boiler was passed into the drum). The drum surface had a temperature of 150 °C, a residence time of 5.5 s, and a drum speed of 10 rpm.

Milling and packaging

The dried chips from each drying method were stored in enclosed polyethylene bags (Ziploc bags) at room temperature (30 ± 2 °C). After which the dried chips of yellow-fleshed sweet potato were milled into flour using No 1 A Hunt Premier mill and the flour was sifted using a laboratory sieve of an aperture screen of 315 µm. The sifted flour was weighed and packaged into high-density polythene bags (Ziploc bags) and kept in a cool dehydrated cupboard before analysis (Osundahunsi et al. (2003).

Determination of physicochemical properties of the flour samples

Proximate composition of the flour samples

The moisture, protein, crude fat, crude fiber, ash, and carbohydrate contents of the flour samples were determined using AOAC (2000) method. pH, bulk density, and particle size of the flour samples were also determined.

pH value

About 10 g of the flour was poured into a beaker and 50 ml of deionized water was added. The pH was determined after mixing the suspension in a beaker (Ngoma et al. 2019). A digital pH meter was used after standardizing with pH 4, 7, and 9 with buffer solutions (Hanna instrument, Woonsocket RI USA, Model HI 98127).

Bulk density (BD)

The BD of yellow-fleshed sweet potato flour for each sample was carried out by measuring 50 g of the flour into a 100 ml graduated cylinder. It was quietly tapped for a few periods on a laboratory work table, till there was no more reduction in the sample volume (Onabanjo & Ighere 2014).

Particle size determination

The mean particle size of the samples was determined using the method of Gbadegesin et al. (2017). The mean particle size of the sample was carried out by measuring 50 g of the samples on a layer of Endecotts sieve. The sieves were arranged on an Endecotts test sieve shaker with the aperture of the sieves declining in the order of 315, 212, 150, 63, 45, 38, and 1 µm. The sieve shaker was operated for 10 min and the percentage of particles withheld on each of the sieves was determined. The percentage withheld and pore diameter of the sieves was used to calculate the mass mean diameter of each sample in Eq. 1 (Gbadegesin et al. 2017)

$$\text{Mass Mean Diameter } (\mu\text{m}) = \sum (\%\text{Mass retained on each sieve} \times \text{sieve aperture})/100 \tag{1}$$

Functional properties determination

Water absorption capacity (WAC)

The analysis of WAC was carried out at room temperature (28 ± 2 °C) using Onwuka (2005) techniques. A gram (w_1) of the sample was poured into a centrifuge tube and measured (w_2), then 10 ml of distilled water was poured into the tube. The content in the tubes was mixed with an electric vortex for 2 min and left to rest at room temperature (28 ± 2 °C) for 30 min. The tubes were centrifuged at 3000 × g for 20 min using a centrifuge (0502-1 Hospibrand, USA). The supernatant was emptied and the remaining content in the tube was drained at a 45° for 10 min and then measured (w_3). The WAC was expressed as a percentage of the volume of water absorbed by the weight of the samples as seen in Eq. (2).

$$\text{WAC } (\%) = \left(\frac{w_3 - w_2}{w_1}\right) \times 100 \tag{2}$$

W_3= weight of the tube+sample after centrifuging and decanting

W_2=weight of tube+sample before centrifuging

W_1=weight of samples

Oil absorption capacity (OAC)

OAC of the flour samples was determined by the modified centrifugation technique of Onwuka (2005). A gram (w_1) of the sample was measured separately into a pre-measured centrifuge tube (w_2) (2 cm in diameter) and 10 ml of Devon King oil was dispersed into the samples. The content was mixed with the oil for 60 s and the mixture was left to rest for 10 min at room temperature and later centrifuged at 1788 × g for 30 min using the centrifuge (TDL-5 BOSCH, England). The oil was carefully poured and the tubes were drained at an angle of 45° for 10 min and weighed (w_3). OAC was calculated as a percentage of the volume of oil absorbed by the samples as shown in Eq. (3);

$$\textit{Oil Absorption Capacity } (\%) = \left(\frac{W_3 - W_2}{W_1}\right) \times 100 \tag{3}$$

-where:

w_1 = weight of Sample

w_2 = weight of tube + sample before centrifuging
w_3 = weight of tube + (sample after centrifuging + decanting

Gelatinization temperature (GT)

GT was carried out by using the techniques of Chavan et al. (2010). One-gram flour sample was measured in triplicate and poured into 20 ml screw-capped tubes, 10 ml of water was added to each sample and was heated gently at 100 °C in a water bath until a solid gel was formed. At complete gel formation, their corresponding temperatures were determined and taken as gelatinization temperature.

Determination of dispersibility

Dispersibility was carried out by using the technique defined by Kulkarni et al. (1991). Ten grams of the sample was weighed into a 100 ml measuring cylinder and water was also added to make up 100 ml. The flour samples and the water added was mixed thoroughly with a glass rod and left to stand for 3 h at room temperature. The volume of stable particles was taken and removed from 100. The differences were described as percentage dispersibility as in Eq. 4.

$$\%Dispersibility = 100 - volume\ of\ the\ settled\ particle \tag{4}$$

Swelling capacity (SC)

SC was analyzed using a modified technique by Badejo et al. (2022). A gram of the sample (w_1) was measured into pre-measured centrifuge tubes and 10 ml of distilled water was added and stirred using a glass rod. The paste obtained was heated individually at a stable temperature of 60 to 90 °C in a water bath for 15 min. When heated, the paste was mixed with a glass rod to avert lump formation. After 15 min, the tubes containing the slurry were centrifuged at 3500 × g for 10 min using a centrifuge (0502-1 Hospibrand, USA). The supernatant was decanted instantly after centrifugation. The centrifuge tubes were dehydrated at 50 °C for 30 min cooled and measured (w_3). Centrifuge tubes containing the sample alone were measured before the addition of distilled water (w_2). Swelling capacity was determined as shown in Eq. (5).

$$\text{Swelling capacity} = \frac{w_3 - w_2}{w_1} \tag{5}$$

w_3=weight of tube +sample after centrifuging and drying
w_2=weight of tube +sample before centrifuging
w_1=weight of the sample

Least gelation concentration (LGC)

LGC was carried out using a modified technique by Coffman and Garcia (1977). The flour samples dispersion of 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, and 30% (w/v) prepared in 5 ml distilled water was heated at 100 °C for 1 h in a water bath. The contents were allowed to cool under a running tap and left for 2 h at 10 ± 2 °C. The least gelation concentration was evaluated as the concentration at which all samples from the inverted tube did not slip.

Pasting properties of determination

The pasting properties of the flour samples were measured by using a Rapid Visco - Analyser model (RVA) with the assistance of a thermocline Windows version 1.1 software (Newport Scientific 1998). Flour suspension was obtained by mixing 3 g of dried samples with distilled water to complete a whole 28 g of suspension in the RVA sample canister. This was positioned at the center of the couple paddle and slotted into the RVA machine. The procedure began at 50 °C temperature for 1 min and raised from 50 – 95 °C for 3 min and later left to rest at 50 °C for more than 4 min. This was continued by holding a temperature of 50 °C for 1 min. The trough viscosity (RVU), peak time (min), pasting temperature (50 – 95 °C), breakdown, final, and setback viscosity (RVU) were determined.

Statistical analysis

All analyses were made in three replicates. The data generated were subjected to a two-way Analysis of Variance (ANOVA) at a 5% level of significance using SPSS 20.0 for Windows. The main and interaction effects of the factors (pretreatments and drying methods) on the quality attributes of the yellow-fleshed sweet potato flour samples were investigated. Means were separated by Duncan's multiple range tests. Descriptive and inferential tools were used to analyze the data obtained.

Results and discussion

Physicochemical properties of the flour samples

Proximate composition of the flour samples

The MC of the samples ranged from 4.88 to 8.46% as depicted in Table 2 which was below the 15.5% suggested for flours (Tortoe et al. 2017, b). The results of the oven-dried samples followed the trend of Ruttarattanamongkol et al. (2016) which obtained the MC of hot air-dried sweet potato flour to range from 4.41 to 4.71%. The MC of five dissimilar species of sweet potato reported by Amajor et al. (2011) ranged from 7.9 to 9.7% and was slightly similar to the values obtained. Oven-dried yellow-fleshed sweet potato flour samples that had

Table 2 Results of Physicochemical Composition of Yellow-Fleshed Sweet Potato Flour Samples

Sample	Moisture Content (%)	Crude Protein (%)	Crude Fats (%)	Crude Fibre (%)	Ash (%)	CHO (%)	Energy (kJ/100 g)
SU	8.37±0.10[a]	5.17±0.04[d]	2.42±0.19[b]	3.89±0.11[d]	1.67±0.03[d]	78.50±0.20[c]	1545.99±1.52[d]
OU	7.75±0.03[b]	7.84±0.05[a]	1.57±0.04[c]	4.88±0.05[b]	2.65±0.03[b]	75.31±0.04[d]	1579.24±1.69[c]
SB	8.46±0.20[a]	7.79±0.05[a]	3.14±0.02[a]	3.39±0.12[e]	2.28±0.09[bc]	74.76±0.23[d]	1597.60±1.74[b]
OB	5.31±0.60[c]	5.20±0.05[d]	1.50±0.01[c]	4.59±0.02[c]	2.29±0.12[c]	81.33±0.21[a]	1578.96±1.94[c]
SS	8.02±0.11[b]	6.08±0.05[c]	2.43±0.09[b]	2.36±0.13[f]	2.37±0.13[bc]	78.76±0.20[c]	1584.73±3.38[c]
OS	4.88±0.11[d]	6.92±0.04[b]	1.62±0.07[c]	4.43±0.04[c]	2.39±0.02[bc]	79.76±0.03[b]	1619.82±2.24[a]
DD	8.46±0.01[a]	5.20±0.06[d]	2.30±0.18[b]	7.81±0.03[a]	3.09±0.25[a]	73.15±0.01[e]	1456.07±4.71[e]

Mean values with the same superscript in a column are not significant ($p<0.05$)

SU Sun-dried (untreated), *OU* Oven-dried (untreated), *SB* Sun-dried (0.02% sulfite, blanched at 85 °C for 3 min 30 s), *OB* Oven-dried (0.02% sulfite, blanched at 85 °C for 3min 30 s), *SS* Sun-dried (0.02% sulfite, Steam blanched for 2 min), *OS* Oven-dried (0.02% sulfite, Steam blanched for 2 min), *DD* Drum-dried (150 °C, 10 rpm, MC - 84.05%)

the least MC are expected to have longer shelf-life and increase flour storage storability and quality because of reduced microbial and chemical activity due to low MC (Li et al. 2017). The high MC of sun and drum-dried yellow-fleshed sweet potato flour samples could lead to caking, an indication categorized by an accumulation of particles into lumps which results in low flour quality and functionality. In Table 2, the results of the crude protein in the flour ranged from 5.17 – 7.84%, which was similar to the values (6.50 - 10.19%) reported by Afolabi et al. (2021). The low protein content in all the flour samples showed that it is not a good source of protein (Konczak-Islam et al. 2003).

From Table 2, the crude fat in the flour samples ranged from 1.50 – 3.14%. The low crude fat content in the samples suggests that it is a poor source of fat. In Table 2, the crude fiber in flour samples ranged from 2.36 to 7.81%. The crude fiber values reported by Obomegbei et al. (2020) were in the range of 2.2 to 3.4% and Sebben et al. (2016) also reported values ranging from 3.20 to 3.46% which correlated with % crude fiber in Table 2. The high amount of crude fiber obtained in drum-dried flour suggest its suitability for making functional foods because it helps to reduce insulin level and postprandial blood sugar in the body (Adeola & Ohizua 2018). Crude fiber when consumed helps in fighting against cardiovascular diseases, and diabetes mellitus reduces diverticulosis, and prevention of digestive diseases (Afolabi et al. 2021). The ash content of the samples ranged from 1.67 to 3.09%. The result implied that the samples had a higher amount of minerals like sodium, magnesium, potassium, iron, and calcium (Torres et al. 2007). The ash content was in the range of 1.8 - 2.8% as reported by Obomegbei et al. (2020) while 2.43 - 2.50% was reported by Afolabi et al. (2021). From Table 2, the carbohydrate content present in yellow-fleshed sweet potato flour samples ranged from 73.15 - 81.33%. The carbohydrate content obtained followed the trend of Haile et al. (2015); which is in the range of 82.3 - 86.5%. It is well known that the flour samples contain carbohydrates that break down gradually, therefore discharging simple sugars steadily into the body, have a tendency to reduce the glycemic level, and thus can be consumed by diabetic patients (Afolabi et al. 2021). The amount of energy or caloric value present in the flour samples in Table 2, ranged from 1456.07 kJ/100 g to 1619.07 kJ/100. All the yellow-fleshed sweet potato flour samples irrespective of their pretreatment methods and drying conditions had the same range of caloric values except for the drum-dried samples that had the least caloric values.

pH, bulk density (BD), and mean particle size of flour samples

The pH of the samples ranged from 5.58 to 6.47 which was in the same trend as the results reported by Tortoe et al. (2017, b) of pH to be 5.80 to 6.20. The treated and drum-dried samples had lower pH values than untreated samples because of the pretreatment given to the treated samples before drying (Olatunde et al. 2016). The range of pH (5.7 to 5.8) posed by Afolabi et al. (2021) followed the trend of this study. The result of the flour samples indicated that all the samples were slightly acidic. The pH of the flour samples is an indication of acidity or alkalinity and its effect on the ability to perform during processing in food industries. In Table 3, the BD of the samples ranged from 0.36 to 0.72 g/ml. The BD results obtained by Patrial et al. (2013) for SP flour ranged from 0.46 to 0.48 g/ml and were greater than the drum-dried result of 0.36 g/ml.

The results of the pretreated samples suggested that blanching affects the compactness of the yellow-fleshed sweet potato flour molecular structure. These results implied that the increase in the BD of the oven and sun-dried flour samples was due to the starch gelatinization procedures that occurred during blanching (Dereje

Table 3 Results for the pH, Bulk Density (BD) and Mean Particle Size of Flour Samples

Sample	pH	Bulk Density (g/ml)	Mean Particle Size (μm)
SU	6.47 ± 0.00^{a}	0.70 ± 0.01^{b}	69.00 ± 1.00^{d}
OU	6.31 ± 0.03^{b}	0.72 ± 0.01^{a}	64.00 ± 0.05^{e}
SB	5.65 ± 0.03^{f}	0.57 ± 0.05^{e}	79.00 ± 1.00^{c}
OB	5.58 ± 0.03^{g}	0.61 ± 0.06^{d}	58.00 ± 2.00^{f}
SS	5.73 ± 0.09^{e}	0.57 ± 0.07^{e}	104.00 ± 2.00^{b}
OS	5.90 ± 0.03^{d}	0.63 ± 0.02^{c}	67.00 ± 1.00^{de}
DD	6.12 ± 0.03^{c}	0.36 ± 0.01^{f}	119.50 ± 0.50^{a}

Mean values with the same superscript in a column are not significant ($p<0.05$)

SU Sun-dried (untreated), *OU* Oven-dried (untreated), *SB* Sun-dried (0.02% sulfite, blanched at 85 °C for 3 min 30 s), *OB* Oven-dried (0.02% sulfite, blanched at 85 °C for 3min 30 s), *SS* Sun-dried (0.02% sulfite, Steam blanched for 2 min), *OS* Oven-dried (0.02% sulfite, Steam blanched for 2 min), *DD* Drum-dried (150 °C, 10 rpm, MC - 84.05%)

et al. 2020). The low BD of drum-dried samples can be connected to the large particle size which can be a result of the flaking of the flour during drum drying, thereby increasing the surface area of the flour samples. The particle size and flour compactness were the parameters that affected the BD of the samples as reported by Igbabul et al. (2014) and Olubunmi et al. (2017). The increase in the BD of the samples may affect packaging in the food industry which can cause an increase in the cost of packaging material required for production in times of thickness but at the advantage of lesser volume to arrive at the weight required (Ngoma et al. 2019). Untreated samples with increased BD have been identified to be used for mixing purposes, while drum-dried samples with decreased BD can be used for the production of baby food (Phuthego 2014).

In Table 3, the mean particle size or mass mean diameter of the yellow-fleshed sweet potato samples ranged from 58 to 119.5μm. Untreated samples had reduced particle sizes compared to the treated samples. This implied that heat treatment before drying contributed to larger particle size. The particle size of drum-dried samples is large because the particles came out as flakes from the drum drier. The particle sizes of all the samples were influenced by milling. The mean particle size of the samples is very important during product handling, packaging, and transportation. The mean particle size is also vital in functional food, surface area, and human digestion (Gbadegesin et al. 2017).

Functional properties of flour samples

Water absorption capacity (WAC)

In Table 4, the water absorption capacity (WAC) of the flour samples ranged from 106.5 to 531%. The WAC of yellow-fleshed sweet potato flour samples is usually known to have different factors that affect the geometry, chemical, conformation, steric factors, protein-related fats and carbohydrates, environment, and thermodynamic properties (Shimelis et al. 2006). The amylose and amylopectin contents of the oven and sun-dried samples may be accountable for the performance of the samples in the presence of water at increased temperatures. WAC of the samples plays a vital role in the functional component of flours used in food processing as it affects the functional and sensory evaluation of food (Dereje et al. 2020). High WAC as observed in drum-dried samples could be related to loosely associated amylose and amylopectin during the pregelatinized process of the slurry after drying (Das et al. 2010).

Oil absorption capacity (OAC)

In Table 4, the OAC of the flours ranged from 83.5 to 168.5%. There was a significant difference ($p<0.05$) between untreated, treated, and drum-dried samples. Blanched and drum-dried samples had higher OAC which can be attributed to their large particle size due to the effect of different processing methods like drying,

Table 4 Results for the Functional Properties of Yellow-Fleshed Sweet Potato Flour Samples

Samples	WAC (%)	OAC (%)	Gelatinization Temperature (°C.)	Dispersibility (%)
SU	119.00 ± 0.00^{b}	83.50 ± 3.50^{c}	81.00 ± 0.50^{ab}	65.00 ± 0.00^{a}
OU	112.00 ± 1.00^{b}	86.50 ± 2.50^{c}	79.25 ± 0.75^{bc}	65.00 ± 0.00^{a}
SB	121.00 ± 1.00^{b}	106.00 ± 1.00^{b}	77.75 ± 0.75^{c}	46.00 ± 0.00^{d}
OB	126.00 ± 0.00^{b}	104.00 ± 1.00^{b}	81.50 ± 0.50^{ab}	62.50 ± 0.05^{b}
SS	106.50 ± 2.50^{b}	100.00 ± 0.00^{b}	79.50 ± 1.00^{abc}	50.00 ± 0.00^{c}
OS	112.00 ± 5.00^{b}	98.00 ± 0.00^{b}	82.50 ± 0.50^{a}	62.00 ± 0.00^{b}
DD	531.00 ± 2.00^{a}	168.5 ± 4.50^{a}	78.50 ± 1.50^{bc}	35.00 ± 0.00^{e}

Mean values with the same superscript in a column are not significant ($p<0.05$)

SU Sun-dried (untreated), *OU* Oven-dried (untreated), *SB* Sun-dried (0.02% sulfite, blanched at 85 °C for 3 min 30 s), *OB* Oven-dried (0.02% sulfite, blanched at 85 °C for 3min 30 s), *SS* Sun-dried (0.02% sulfite, Steam blanched for 2 min), *OS* Oven-dried (0.02% sulfite, Steam blanched for 2 min), *DD* Drum-dried (150 °C, 10 rpm, MC - 84.05%)

milling, and pretreatments. The effect of different processing methods increased the OAC of the flour samples and this could be due to the presence of greater amounts of hydrophobic constituents in the flour and the larger particle size during pretreatment (blanching and steam blanching) which can be attributed to the heating methods (Kaur & Singh 2006). The OAC of flour is the ability to absorb oil through an active mechanism of capillary attraction (Ndie et al. 2010). The OAC of the samples is vital as it improves mouthfeel and preserves flavor (Igbabul et al. 2014).

Gelatinization temperature (GT) & dispersibility

The gelatinization temperature (GT) of the samples ranged from 77.75 to 82.5 °C. The temperature upon which the cooking of starch occurs is regarded as GT (Sahay & Singh 1996). The dispersibility of the samples ranged from 35 to 65%. Oven and sun-dried samples had higher dispersibility compared to drum-dried samples which had lower dispersibility. Dispersibility is temperature and particle size-dependent (Igyor et al. 2010). The higher the dispersibility of oven and sun-dried samples, the better the samples are reconstituted in water (Oluwole et al. 2016).

Swelling capacity (SC)

The swelling capacity (SC) of the samples is presented in Fig. 1. SC of a food product determines the amount of linked strength contained by its starch particles (Igbabul et al. 2014). SC is also the ability of starch particles to hold or absorb water (Soison et al. 2015). The SC of the samples was in the range of 101 – 308% at 60 °C**.** The SC of drum-dried samples increased from 60 to 80 °C and then decreased at 90 °C. This indicated that the samples had an optimal water uptake at 80 °C. For other samples, 70 °C was a defining point for the SC of the products which implies that the SC of the samples doubled the results of the SC at 60 °C. Similar to the findings reported by Afolabi et al. (2021), the SC of the oven and sun-dried samples increased with a rise in temperature as shown in Fig. 1. The swelling capacity of the samples was dependent on the effect of the temperature of rehydrating water.

The influence of drying methods and pretreatment was significant ($P<0.05$) (Desalegn & Kibr 2021). The drying method and pretreatment had a significant influence on the swelling capacity of the yellow-fleshed sweet potato flour samples (Fig. 1). The particle size of the starch component, protein, and functional properties such as viscosity, gelatinization, and temperature of the yellow-fleshed sweet potato flour samples have been described to significantly affect their SC. The variation in the SC of drum-dried samples could be a result of pregelatinized starch granules which occurred during drum-drying causing thinning and inability of the starch to further gelatinize. Unlike the oven and sun-dried samples, the SC values for the drum-dried flour were quite stable with an increase in temperature (Soison et al. 2015). Table 5 show the regression relationships between the percentage (%) SC

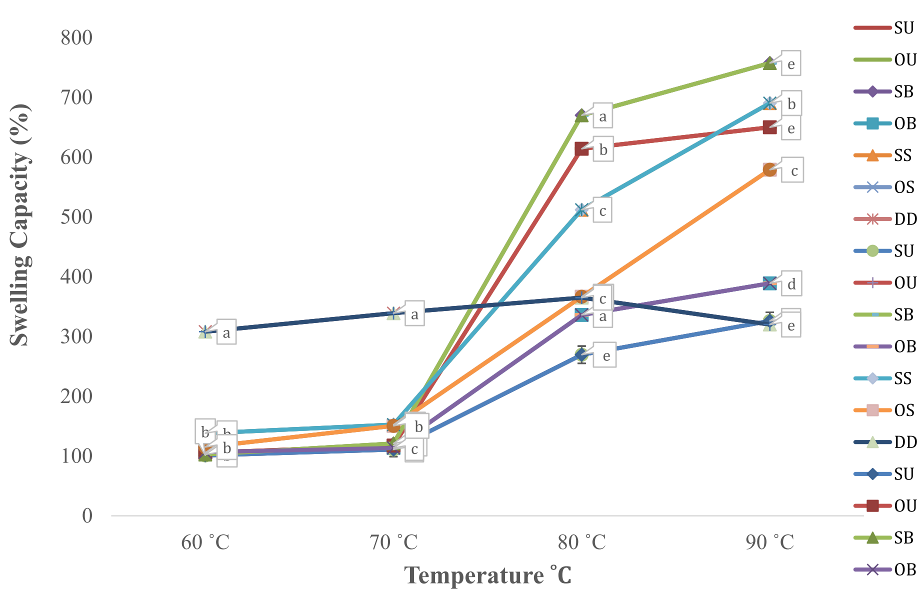


Fig. 1 SC of Yellow-Fleshed Sweet Potato Samples at Different Temperatures. Mean values with the same superscript on y-axis are not significant ($p<0.05$). SU - Sun-dried (untreated), OU – Oven-dried (untreated), SB- Sun-dried (0.02% sulfite, blanched at 85 °C for 3 min 30 s), OB – Oven-dried (0.02% sulfite, blanched at 85 °C for 3min 30 s), SS – Sun-dried (0.02% sulfite, Steam blanched for 2 min), OS – Oven-dried (0.02% sulfite, Steam blanched for 2 min), DD – Drum-dried (150 °C, 10 rpm, MC - 84.05%

Table 5 Regression relationships between (%) Swelling Capacity of Yellow-Fleshed Sweet Potato Flour Samples at Different Temperatures

Samples	Linear equation	R^2	Logarithmic equation	R^2	Polynomial equation	R^2	Power equation	R^2
SU	$y = 81.183x$	0.9035	$y = 169.14\ln(x) + 67.495$	0.8074	$y = 3.2984x^2 + 70.189x$	0.9094	$y = 86.244x^{0.906}$	0.8224
OU	$y = 159.42x$	0.7717	$y = 438.7\ln(x) + 23.196$	0.7682	$y = 27.089x^2 + 69.12x$	0.8275	$y = 82.066x^{1.4764}$	0.7823
SB	$y = 179.48x$	0.7778	$y = 514.95\ln(x) + 3.6119$	0.7847	$y = 38.137x^2 + 52.36x$	0.8598	$y = 78.831x^{1.60288}$	0.8037
OB	$y = 96.583x$	0.8682	$y = 217.91\ln(x) + 63.118$	0.7898	$y = 7.2661x^2 + 72.363x$	0.8849	$y = 88.417x^{1.02344}$	0.7942
SS	$y = 157.97x$	0.8572	$y = 404.84\ln(x) + 51.477$	0.7945	$y = 29x^2 + 61.3x$	0.9349	$y = 109.91x^{1.2369}$	0.8137
OS	$y = 127.72x$	0.8841	$y = 320.48\ln(x) + 48.123$	0.8022	$y = 24.573x^2 + 45.808x$	0.9740	$y = 96.234x^{1.1822}$	0.8855
DD	$y = 112.03x$	-36.14	$y = 19.639\ln(x) + 317.4$	0.2255	$y = -54.887x^2 + 294.44x$	-2.563	$y = 316.96x^{0.0595}$	0.2342

SU Sun-dried (untreated), *OU* Oven-dried (untreated), *SB* Sun-dried (0.02% sulfite, blanched at 85 °C for 3 min 30 s), *OB* Oven-dried (0.02% sulfite, blanched at 85 °C for 3min 30 s), *SS* Sun-dried (0.02% sulfite, Steam blanched for 2 min), *OS* Oven-dried (0.02% sulfite, Steam blanched for 2 min), *DD* Drum-dried (150 °C, 10 rpm, MC - 84.05%)

of yellow-fleshed sweet potato flour samples at different temperature (from 60 to 90 °C). Linear, logarithm, polynomial, and power model equations were used to analyze the parameters (swelling capacity and temperature) interaction and show the correlation coefficient r^2 between the samples.

For oven and sun-dried samples, the polynomial equation gave the highest r^2 values followed by the linear equation. Non-drum dried samples best described by a polynomial equation between the r^2 values were highest. Drum-dried samples were difficult to establish a mathematical relationship between SC and temperature.

Least gelation concentration (LGC)

The LGC of the samples is presented in Table 6. There was a significant difference ($p < 0.05$) in the LGC of the samples between 2 to 10% but there was no significant difference ($p > 0.05$) in the LGC among the samples at 12 to 30%.

The results obtained following the trend of Sathe et al. (1983) that reported LGC of 12% for black gram flour and other flour such as lupin (Sathe et al. 1982), plantain, safflower, and maize flour (Akubor 1997) was 14, 6,8 and 6% (w/v). The higher the (LGC) of the samples, the higher their ability to form a stable gel, all the yellow-fleshed sweet potato flour samples formed a stable gel at 12% (w/v). The results suggest that the LGC of the oven and sun-dried samples will be important in food processing such as desserts, pottage, and foods that need thickener (Onimawo 2006).

Pasting properties of the yellow-fleshed sweet potato flour samples

The pasting properties of the samples are presented in Table 7. The results have shown that the value of peak viscosity ranged from 66.50 to 114.67 RVU, trough viscosity (18.13 to 80.33 RVU), breakdown viscosity (19.25 to 49.76 RVU), final viscosity (24.88 to 124.58 RVU), setback viscosity (6.75 to 43.75 RVU), peak time (1.07 to 4.67 min), and peak temperature (0 to 94.45 °C). The results in Table 7 showed that the peak time, pasting temperature, trough viscosity, final viscosity, and setback

Table 6 Least Gelation Concentration (LGC) of Yellow-Fleshed Sweet Potato Flour Samples

Samples	Concentration (%, w/v)										
	2	4	6	8	10	12	14	16	20	22	30
SU	-	±	±	±	+	+	+	+	+	+	+
OU	±	±	±	±	+	+	+	+	+	+	+
SB	-	±	±	±	+	+	+	+	+	+	+
OB	-	-	±	±	+	+	+	+	+	+	+
SS	-	+	+	+	+	+	+	+	+	+	+
OS	-	±	±	±	+	+	+	+	+	+	+
DD	-	+	±	±	±	+	+	+	+	+	+

-no gelation + partial gelation ± complete gelation

SU Sun-dried (untreated), *OU* Oven-dried (untreated), *SB* Sun-dried (0.02% sulfite, blanched at 85 °C for 3 min 30 s), *OB* Oven-dried (0.02% sulfite, blanched at 85 °C for 3min 30 s), *SS* Sun-dried (0.02% sulfite, Steam blanched for 2 min), *OS* Oven-dried (0.02% sulfite, Steam blanched for 2 min), *DD* Drum-dried (150 °C, 10 rpm, MC - 84.05%)

Table 7 Pasting Profile of Yellow-Fleshed Sweet Potato Flour Samples

Sample	Peak Viscosity (RVU)	Trough Viscosity (RVU)	Breakdown Viscosity (RVU)	Final Viscosity (RVU),	Setback Viscosity (RVU)	Peak Time (min)	Pasting Temperature (°C)
SU	75.71 ± 0.46[d]	56.46 ± 0.46[e]	19.25 ± 0.02[f]	72.83 ± 0.75[e]	16.38 ± 0.29[f]	4.67 ± 0.06[a]	80.70 ± 0.04[a]
OU	86.17 ± 1.17[c]	62.00 ± 0.75[d]	24.17 ± 0.42[c]	86.63 ± 1.46[d]	24.63 ± 0.71[d]	4.60 ± 0.09[ab]	94.45 ± 0.40[a]
SB	114.67 ± 0.08[a]	80.33 ± 0.42[a]	33.83 ± 0.50[b]	124.58 ± 0.02[a]	43.75 ± 0.42[a]	4.53 ± 0.08[b]	80.60 ± 0.50[a]
OB	66.50 ± 1.08[e]	47.21 ± 0.96[f]	19.27 ± 0.13[d]	69.75 ± 1.67[e]	22.54 ± 0.71[e]	4.53 ± 0.09[b]	74.60 ± 4.50[a]
SS	93.58 ± 0.25[b]	72.08 ± 0.08[b]	21.50 ± 0.17[e]	107.08 ± 0.50[b]	35.00 ± 0.58[b]	4.53 ± 0.07[b]	80.75 ± 0.40[a]
OS	87.42 ± 0.58[c]	64.25 ± 0.58[c]	23.17 ± 0.00[f]	94.00 ± 1.08[c]	29.75 ± 0.50[c]	4.67 ± 0.06[a]	79.45 ± 0.40[a]
DD	84.03 ± 0.08[e]	18.13 ± 0.04[g]	49.76 ± 0.04[a]	24.88 ± 0.04[f]	6.75 ± 0.05[g]	1.07 ± 0.02[c]	0.00 ± 0.07[b]

Mean values with the same superscript in a column are not significant ($p<0.05$)

SU Sun-dried (untreated), *OU* Oven-dried (untreated), *SB* Sun-dried (0.02% sulfite, blanched at 85 °C for 3 min 30 s), *OB* Oven-dried (0.02% sulfite, blanched at 85 °C for 3min 30 s), *SS* Sun-dried (0.02% sulfite, Steam blanched for 2 min), *OS* Oven-dried (0.02% sulfite, Steam blanched for 2 min), *DD* Drum-dried (150 °C, 10 rpm, MC - 84.05%

viscosity were significantly lower for the pregelatinized drum-dried flours than untreated and treated samples.

The peak viscosity results indicated that the degree of starch swelling of the oven and sun-dried samples resonated by their peak value that specified the viscous consistency or pastes formation that occurred during mixing (Lim 2016). The trough viscosity is the least viscosity value in the constant temperature period of the pasting profile of flour samples which determines the capability of sweet potato paste to tolerate breakdown during cooling (Isibhakhomen et al. 2013; Ojo et al. 2017). The values of breakdown viscosity obtained in this study are lower than the breakdown viscosity (63-72.5RVU) obtained in 100% peeled and unpeeled orange-fleshed sweet potato flour (Chikpah et al. 2020). Breakdown in viscosity of cooked pastes of all the samples denotes their stability to shearing during cooking (Beta & Corke 2001). A low breakdown value of oven and sun-dried samples suggest the stability of starches under hot environments (Asaam et al. 2018). Drum-dried samples had high breakdown viscosity values which show that it has a lesser capacity to withstand heat and shear stress during cooking (Adebowale et al. 2017). The trough viscosity (33.5-36.0 RVU) and final viscosity (50.0-52.0 RVU) of the 100% peeled and unpeeled orange-fleshed sweet potato measured the results of Chikpah et al. (2020) were lower than the trough viscosity and final viscosity obtained in this study. The final viscosity of the samples at the cooling phase suggests the ability of the starch-based food to form a gel or paste after cooking and during cooling (Ndie et al. 2010). Yellow-fleshed sweet potato flours produced from a drum drier have less viscosity and this can be used in batters for coating different food products, in confectionery industries as binders and film formers, and in dairy industries as texturizers (Dereje et al. 2020). Drum-dried samples with low viscosity can be used in making food product preparations to attain the required properties with increased solids per unit volume (Yadav et al. 2007). The setback viscosity of flour is the ability of paste or slurry formed to tolerate heat. Its shear stress is important in the determination of rheology properties of some food products that require constant paste (Adebowale et al. 2017). Setback values of drum-dried samples exhibited a lower tendency for retrogradation (Akinyele et al. 2020; Li et al. 2018). Although drum-dried samples that had lesser viscosity may be useful for products that require low gel strength and elasticity (Tharise et al. 2014). Setbacks of the oven and sun-dried samples are used to depict the retrogradation tendency of cooked pastes and this occurs when pastes are cooled. This phenomenon is characterized by gelling and an increase in firmness and rigidity of pastes, loss of paste clarity which occurs as a result of the rearrangement of amylose, and reversible crystallization of amylopectin molecules (Tortoe et al. 2017, b). The peak time of the samples ranged from 1.07 to 4.67 min. Drum-dried samples had the least peak time of 1.07 min other samples had a higher peak time. There was a significant difference ($p<0.05$) between drum-dried samples and other samples. The peak time of untreated and treated samples are within the range of values (4.90-6.66 min) obtained in the pasting results of Afolabi et al. (2021). Low peak viscosity time decreased the product's gel ability which is a reflection of gelation. This agrees with the earlier suggestion that drum-dried samples had almost fully gelatinized during production. Peak time replicates the period in which the flour samples will take to get to their particular peak viscosity (Ndie et al. 2010). The function of the flour samples in food processing industries is dependent on the pasting performance of their starches, and this makes available useful information in the development of new products (Tortoe et al. 2017, b). The pasting temperature of the sun and oven-dried samples ranged from 74.60 - 94.45 °C while the drum-dried sample was 0 °C. The peak temperature of untreated and treated yellow-fleshed sweet potato flour samples measured in this study is slightly similar to the peak temperature (78.19-88.33 °C) obtained in the work of Afolabi et al. (2021). The pasting temperatures (83.90 - 83.98 °C and 80.0-85.0 °C) obtained by Chikpah et al. (2020) and Ruttarattanamongkol et al. (2016) are within the range of values obtained in this study. The lowest temperature needed for cooking is known as the pasting temperature (Shimelis et al. 2006). The low temperature (0 °C) for gelatinization was concluded during drum drying such that no new gel was formed during the pasting test. Low pasting temperature as seen in the drum-dried samples implied that the flour does not require much energy during cooking and this is a very important criterion in the production of baby food or formulation of infant food products compared to other samples (Dereje et al. 2020). The result is a confirmation that gelatinization was extensive during drum drying. It was observed from the pasting profile that drum drying affected the pasting temperature of the drum-dried samples because the drying method cooked the samples hence, zero pasting temperature was observed (Ruttarattanamongkol et al. 2016).

Conclusion

The pretreatment and drying techniques significantly affected the moisture content, carbohydrates, ash, fiber, pH, bulk density, particle size, water absorption capacity, oil absorption capacity, dispersibility, least gelation, swelling capacity, and pasting properties of yellow-fleshed sweet potato flour samples. This study revealed that the pretreatment and drying methods affected the quality properties of the yellow-fleshed sweet potato flour samples in a different way, consequentially altering their functionality.

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Authors' contributions

All authors conceived the work. OA carried out the laboratory work. All authors were involved in data analysis and interpretation. OA was a major contributor to manuscript development. TA and KA were major contributors to proofreading the manuscripts. All authors read and approved the final manuscript.

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Availability of data and materials

The data generated or analyzed during this study are available from the corresponding author at the reasonable request

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

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Competing interests

The authors declare that they have no competing interests.

Author details

[1]Department of Food Science and Technology, Obafemi Awolowo University, Ile - Ife, Osun State, Nigeria.

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