Journal of
Food Science & Food Products
https://acadpub.com/jfsfp

Effects of Vegetable Oil and Sodium Bicarbonate on the Pasting and Functional Properties of Boiled *Mucuna utilis* Flour

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Research Article

How to Cite:
Attaugwu RN, Anyadioha JI, Osinachi NM, Effects of vegetable oil and sodium bicarbonate on the pasting and functional properties of boiled *Mucuna utilis* Flour. *J Food Sci Food Prod.* 2026;2:13-19.

Keywords:
Functional properties, *Mucuna utilis* flour, pasting characteristics, sodium bicarbonate treatment, vegetable oil

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ABSTRACT

Objective: This study aimed to evaluate the effects of vegetable oil and sodium bicarbonate addition on the pasting and functional properties of boiled *Mucuna utilis* flour. The research sought to improve the nutritional and functional quality of this underutilized legume, which is naturally rich in protein and dietary fiber but requires processing to enhance its usability in food systems. **Materials and Methods:** *Mucuna utilis* seeds were boiled and subsequently treated with varying levels of vegetable oil and sodium bicarbonate. The pasting characteristics-including peak viscosity, breakdown, setback, and final viscosity-were determined using a Rapid Visco Analyzer (RVA). Functional properties such as water absorption capacity, oil absorption capacity, swelling power, bulk density and dispersibility were measured following standard laboratory protocols. **Results:** The incorporation of vegetable oil and sodium bicarbonate significantly influenced both pasting and functional properties of *Mucuna utilis* flour. Additive treatments generally reduced peak viscosity and setback, indicating improved digestibility and reduced retrogradation tendency. Sodium bicarbonate enhanced water absorption and swelling capacity, whereas vegetable oil increased dispersibility and oil absorption capacity. **Conclusion:** The results demonstrate that the addition of vegetable oil and sodium bicarbonate during processing can enhance the functional versatility of *Mucuna utilis* flour. These modifications improve its textural and storage characteristics, making it more suitable for diverse culinary and industrial food applications.

INTRODUCTION

Protein-energy malnutrition remains a major public health concern in tropical developing regions, particularly in Nigeria, where the rapidly increasing population and the high cost of animal-derived protein have resulted in a strong dependence on cereal-based diets characterized by poor protein quality[1]. Despite global initiatives, current interventions have not adequately addressed the underlying causes of food insecurity and malnutrition, leaving a significant portion of the population susceptible to nutrient deficiencies. This challenge underscores the urgent need to identify affordable, nutrient-dense, plant-based protein sources to mitigate the existing protein gap.

Legumes are increasingly recognized as sustainable and cost-effective sources of high-quality protein, essential amino acids, dietary fiber and micronutrients[2]. However, commonly consumed legumes such as soybean and cowpea, though nutritionally valuable, are often insufficient to meet the rising demand due to production and supply limitations[3]. Consequently, scientific attention has increasingly focused on underutilized legumes with comparable or superior nutritional and functional attributes. Among these, Mucuna species have emerged as promising alternatives due to their high protein content, substantial dietary fiber, appreciable levels of unsaturated fatty acids, and essential mineral composition[4]. Attaugwu et al.[5] also demonstrated its functional potential as a soup thickener, indicating its versatility in food formulations.

Although several studies have examined the nutritional composition of *Mucuna* species, limited information is available regarding the influence of functional additives such as vegetable oil and sodium bicarbonate on the processing characteristics of *Mucuna utilis* flour. Therefore, this study seeks to evaluate the effects of these additives on the functional and pasting properties of boiled *Mucuna utilis* flour, thereby contributing to the understanding of its potential utilization in food systems and its role in alleviating protein-energy malnutrition.

MATERIALS AND METHODS

Source of raw materials: *Mucuna utilis* seeds were purchased from Oba Market, Nsukka, Enugu State, Nigeria. Vegetable oil, sodium bicarbonate, and other analytical reagents were sourced from Ogbete Main Market, Enugu.

Preparation of boiled *Mucuna utilis* flour: One kilogram (1.0 kg) of dried *Mucuna utilis* seeds was boiled at 100°C for 15 min to enhance water absorption, soften the seed coats, and reduce the presence of anti-nutritional factors. The boiled seeds were manually dehulled, oven-dried at 60°C for 48 hrs and subsequently milled using a Panasonic mixer grinder. The resulting flour was sieved to obtain a uniform particle size, packed in airtight containers and stored under refrigerated conditions until further analysis. A process flow diagram is presented in Fig. 1.

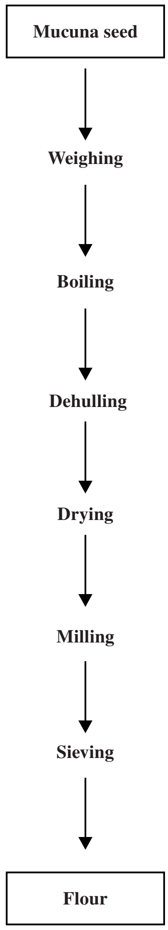

Fig. 1: Procession of boiled *Mucuna utilis* flour

Experimental design: The experimental design was developed using Minitab software version 14.0. A total of 15 experimental runs were generated to investigate the interactive effects of three independent variables: Sodium bicarbonate quantity (g) (A), vegetable oil quantity (g) (B), and *Mucuna utilis* seed flour (C). The independent variables and their various levels are shown in Table 1.

Table 1: Experimental design

Run	Na (HCO_3)	Vegetable Oil	Mucuna flour
1	1.5	3	40
2	1.0	3	30
3	2.0	4	40
4	1.5	3	40
5	1.5	3	40
6	1.5	2	50
7	2.0	2	40
8	1.5	4	50
9	1.0	2	40
10	1.0	4	40
11	1.0	3	50
12	2.0	3	30
13	1.5	4	30
14	2.0	3	50
15	1.5	2	30

Functional properties determination of flour: The functional properties of the flour samples were evaluated to determine the functional behavior of their protein components. The following properties were analyzed:

Oil absorption capacity: Oil absorption capacity was determined following the method described by Fidaleo et al.[6] with slight modifications. Briefly, 0.5 g of each flour sample was mixed with 6 mL of oil in pre-weighed centrifuge tubes and shaken vigorously for 5 min. The mixtures were then allowed to stand undisturbed for 30 min at 25°C. After the resting period, excess oil was decanted, and the tubes were reweighed to determine the amount of oil absorbed.

OAC (g/g) was calculated as per equation (1):

$$\text{OAC(g / g)}=\frac{\text{Weight of tube after removal of excess oil-Weight of tube-Weight of sample}}{\text{Weight of sample}} \quad (1)$$

Emulsification capacity: Emulsification capacity was determined according to the method described by AOAC[7]. One gram of flour was homogenized with 5 mL of distilled water for 30 sec, after which 5 mL of vegetable oil was added and the mixture was further blended for an additional 30 sec. The resulting emulsion was centrifuged at 1600 rpm for 10 min and the volume of the emulsified layer was recorded to determine the emulsification capacity.

$$\text{Emulsifying capacity (\%)} = \frac{\text{Volume of emulsified layer}}{\text{Tota volume of mixture}} \times \frac{100}{1} \quad (2)$$

Swelling index determination:

$$\text{OAC} = \text{Total oil added-Free oil (supernatant)} \times \text{Density of oil} \quad (3)$$

OAC: Oil absorption capacity

Swelling index: The swelling index and related functional properties of taro flour were determined following established methods for evaluating water absorption, solubility and swelling capacity in taro flour samples[8]. A 3.0 g sample of flour was placed in a clean 50 mL graduated cylinder and the initial volume was recorded. Subsequently, 30 mL of distilled water was added and the mixture was gently swirled to ensure proper mixing. The cylinder was allowed to stand undisturbed at room temperature for 60 min. Volume readings were taken at 15 min intervals (15, 30, 45 and 60 min) to assess the extent of swelling.

Bulk density: Bulk density was determined following the method outlined by AOAC[7]. A 10 mL graduated cylinder was weighed, filled with flour and tapped gently until the volume became constant. The bulk density was then calculated as the ratio of the sample weight to its settled volume and expressed in g/mL.

Calculation:

$$\text{Bulk density (g/mL)} = \frac{\text{Weight of sample (mL)}}{\text{Volume of sample (mL)}} \quad (4)$$

Water absorption capacity: Water Absorption Capacity (WAC) was determined using the method of Fidaleo et al.[6] with slight modifications. Three grams of flour were mixed with 25 mL of distilled water in a pre-weighed centrifuge tube, shaken for 5 min and allowed to stand for 30 min at room temperature. The mixture was then centrifuged at 3000 g for 25 min, the supernatant discarded and the tubes dried at 50°C for 25 min. WAC (g/g) was calculated based on the weight gain of the sample.

$$\text{Water absorption capacity} = \frac{\text{Weight of tube with sample after drying -weight of tube-weight of sample}}{\text{Weight of sample}} \quad (5)$$

Pasting properties: The pasting properties of cassava flour were determined using a Rapid Visco Analyzer (RVA) (Newport Scientific, Warriewood, Australia) following the General Pasting Method (STD1)[9]. Three grams (3 g) of flour were dispersed in 25.0 mL of distilled water within an RVA canister. The resulting slurry was stirred and subjected to a controlled heating and cooling cycle: initially heated from 50-95°C, held at 95°C for 2 min and subsequently cooled to 50°C at a rate of 11.25°C/min. Stirring speeds were set at 960 rpm during the first 10 sec and maintained at 160 rpm for the remainder of the test. Pasting parameters, including peak viscosity, trough viscosity, final viscosity, peak time, and pasting temperature, were recorded using Thermocline for Windows software. Viscosity values were expressed in Rapid Visco Units (RVU)[10].

Statistical analysis: Data from each experimental run were statistically regressed and subjected to one-way analysis of variance (ANOVA) using both SPSS and Minitab software. Statistical significance was established at the 5% probability level ($p \leq 0.05$). Graphical representations of significant fitted responses were generated using Minitab software (version 14.0) to facilitate clearer visualization of treatment effects.

RESULTS AND DISCUSSION

Effect of sodium bicarbonate and vegetable oil on functional properties of *Mucuna utilis* flour: The functional properties of boiled Mucuna flour have been reported to include notable Oil Absorption Capacity (OAC), which is an important attribute for food formulations as it can enhance flavour retention and mouthfeel in products[11]. Mucuna bean flours in several species have demonstrated high OAC and other functional properties suitable for food applications (Functional and physicochemical properties of mucuna bean flours).

Bulk density values ranged from 0.47-0.70 g/mL, which are comparable to those reported by Adebowale[12] for water yam flour. Increasing levels of sodium bicarbonate and oil tended to lower bulk density, although all samples retained acceptable values for thickening and formulation purposes. Since bulk density is largely dependent on starch structure, it plays a critical role in determining storage, packaging, and handling properties[13].

Water Absorption Capacity (WAC) ranged between 1.20 and 1.93 g/g, corroborating the results reported by Du et al.[14]. Elevated WAC values indicate strong interactions between sodium bicarbonate and the flour matrix, likely facilitated by the presence of hydrophilic constituents such as polysaccharides and polar amino acid residues that enhance water binding[15]. Conversely, samples with higher oil content exhibited lower Water Absorption Capacity (WAC), presumably due to hydrophobic interference restricting water uptake. High WAC is a desirable trait in bakery formulations, as it improves dough handling, yield, and textural attributes[16].

The OAC values of boiled *Mucuna utilis* flour (1.24-1.80 g/g) were highest in samples treated with both vegetable oil and sodium bicarbonate, suggesting enhanced hydrophobic interactions. This observation agrees with earlier findings that chemical or thermal treatments improve OAC[17]. Moderate Oil Absorption Capacity (OAC) indicates suitability for bakery applications[18], while comparatively low OAC may be due to limited protein denaturation or absence of functional additives. Functional properties such as WAC and OAC of processed flours have been shown to vary with processing methods, with implications for product quality in baked foods[19]. Enhanced OAC enhances product structure, flavor retention, and shelf stability, making the flour a potential ingredient in oil-rich formulations such as meat analogues and baked products[16,18].

Emulsion capacity ranged from 36.68-66.68%, with the highest values observed in samples containing greater quantities of vegetable oil. This enhancement may be attributed to protein molecules stabilizing oil-in-water emulsions, suggesting that *Mucuna utilis* flour could serve as a functional ingredient in emulsified food systems, including mayonnaise, salad dressings, and processed meats[20]. Emulsion capacity (EC) reflects the ability of food matrices to bind oil and water, which is primarily governed by surface-active nonpolar amino acids, proteins, and associated components[16].

The swelling index varied from 1.26-2.25, with the highest values recorded in samples BMFE and BMFN. Lower swelling indices in samples with higher additive levels may be attributed to restricted water penetration and partial disruption of starch granule integrity. Swelling behavior is influenced by starch molecular organization and the interactions of added components. It reflects the extent of noncovalent bonding among starch molecules and is affected by the amylose-to-amylopectin ratio[21]. Flours exhibiting high swelling capacity are especially suited for use as thickeners in soups, sauces and gravies (Table 2)[11].

Pasting properties of treated *Mucuna utilis* flour: The pasting characteristics of boiled *Mucuna utilis* flour treated with sodium bicarbonate and vegetable oil are presented in Table 3.

Peak viscosity: Peak viscosity values ranged from 35.5-68.58 RVU, with sample BMFK exhibiting the lowest and BMFM the highest. These results are comparable to pasting characteristics reported for composite flours containing legume components, which showed peak viscosities within similar ranges[22]. The generally lower peak viscosity observed in this study indicates limited starch granule swelling, which may be attributed to partial structural disintegration resulting from boiling (pre-gelatinization) and the disruptive influence of oil and alkali on starch molecular organization[23].

Trough viscosity: Trough viscosity ranged from 6.95-14.54 RVU, significantly lower ($p \leq 0.05$) than values reported for untreated flour. This reduction suggests enhanced stability of the starch paste during heating, as the modified starch molecules exhibited increased resistance to shear and thermal breakdown under constant high-temperature conditions[24].

Breakdown viscosity: Breakdown viscosity, defined as the difference between peak and trough viscosities, ranged from 26-55.5 RVU. Although, no significant differences were detected among most samples, the observed values indicate that the starches demonstrated moderate to high resistance to mechanical shear and thermal stress, likely due to partial gelatinization and reorganization of granular structure. These values were slightly lower than those reported for toasted maize-soy-tigernut blends (5-81 RVU)[25] and wheat-plantain-tigernut flour (64-87 RVU)[26], possibly due to the hydrothermal pre-treatment and the influence of protein-lipid interactions in *Mucuna utilis* flour.

Final viscosity: Final viscosity ranged between 12 and 21 RVU, which is substantially lower than values typically reported for untreated legume flours. This reduction in final viscosity may reflect altered starch gelatinization and paste

Table 2: Functional properties of mucuna flours

Samples	OAC (g/g)	Emulsion (%)	Swelling Index	BD (g/ml)	WAC (g/g)
BMFA	1.24±0.01[f]	36.69±0.02[f]	1.99±0.01[a]	0.56±0.01 [b]	1.10±0.00[b]
BMFB	1.46±0.00[d]	63.34±0.01[b]	1.98±0.02[a]	0.69±0.01[a]	1.89±0.01[a]
BMFC	1.46±0.00[d]	50.00±0.00[d]	1.37±0.03[c]	0.54±0.01[b]	1.17±0.01[g]
BMFD	1.69±0.01[b]	40.00±0.00[e]	2.00±0.00[a]	0.70±0.01[a]	1.93±0.01[a]
BMFE	1.52±0.04[d]	60.05±0.01[b]	1.49±0.01[c]	0.69±0.00[a]	1.89±0.08[a]
BMFF	1.30±0.01[f]	40.00±0.00[e]	1.49±0.001[c]	0.52±0.01[c]	1.39±0.01[f]
BMFG	1.53±0.01[d]	36.68±0.02[f]	1.49±0.00[c]	0.65±0.01[b]	1.50±0.04[e]
BMFH	1.50±0.01[d]	66.68±0.02[a]	2.25±0.01[a]	0.52±0.01[cb]	1.79±0.01[e]
BMFI	1.61±0.02[c]	50.00±0.00[d]	1.75±0.01[b]	0.47±0.01[b]	1.38±0.02[f]
BMFJ	1.78±0.16[a]	50.00±0.00[d]	1.99±0.01[a]	0.50±0.01[b]	1.49±0.01[c]
BMFK	1.40±0.01[e]	50.00±0.02[d]	1.26±0.01[c]	0.50±0.01[b]	1.19±0.01[a]
BMFL	1.80±0.01[a]	46.65±0.01[d]	1.49±0.01[c]	0.68±0.01[a]	1.79±0.01[b]
BMFM	1.60±0.08[c]	56.66±0.01[c]	1.99±0.01[a]	0.70±0.01[a]	1.93±0.01[a]
BMFN	1.60±0.00[c]	60.00±0.02[b]	2.00±0.01[a]	0.51±0.01[b]	1.10±0.01[a]
BMFO	1.70±0.01[b]	56.00±0.00[c]	1.89±0.01[a]	0.65±0.01[b]	1.67±0.04[a]

Mean values±standard deviations with different alphabetical superscripts in the same row are significantly different at $p \leq 0.05$. Key: Samples BMFA through Sample BMFO: Boiled mucuna flour A to Z, OAC: Oil absorption capacity, WAC: Water absorption capacity and BD: Bulk density

Table 3: Pasting Properties of mucuna flour

Samples	Peak	Trough	Break	Final	Set	Time	Temp
BMFA	46.25±0.46^{e}	12.25±0.59^{a}	34.00^{c}±0.11^{c}	19.33±0.94^{a}	7.08±0.35^{a}	6.00±0.0^{a}	94.90±0.00^{b}
BMFB	45.25±8.48^{e}	12.25±0.59^{a}	27.12±5.48^{d}	19.33±0.94^{b}	12.00±5.48^{d}	5.82±5.48^{d}	94.12±5.48^{d}
BMFC	46.25±0.46^{e}	12.25±0.59^{a}	34.00±0.11^{c}	19.33±0.94^{a}	7.08±0.35^{a}	6.00±0.00^{a}	94.90±0.00^{b}
BMFD	36.79±8.89^{f}	9.66±3.41^{b}	34.00±0.11^{c}	12.00±0.80^{d}	7.08±0.35^{a}	6.00±0.00^{a}	95.05±0.00^{b}
BMFE	36.79±8.89^{f}	9.45±1.94^{b}	35.79±6.54^{c}	12.00±0.80^{d}	6.08±0.65^{a}	6.13±0.04^{a}	95.05±0.00^{b}
BMFF	49.95±0.53^{e}	13.21±0.29^{a}	36.75±0.24^{c}	19.87±0.64^{a}	6.08±0.35^{a}	6.13±0.00^{a}	95.05±0.00^{b}
BMFG	59.79±3.35^{e}	13.08±1.64^{a}	46.71±1.71^{b}	20.00±1.76^{a}	6.91±0.12^{a}	5.80±0.00^{a}	95.06±0.07^{b}
BMFH	41.96±4.29^{e}	11.92±1.76^{a}	30.04±2.53^{c}	18.50±2.47^{b}	6.58±0.70^{a}	6.06±0.09^{a}	95.02±0.03^{a}
BMFI	41.21±1.71^{e}	14.54±0.53^{a}	26.66±1.18^{d}	21.40±0.82^{a}	6.87±0.28^{a}	6.13±0.19^{a}	95.05±0.00^{b}
BMFJ	60.96±7.12^{c}	10.50±0.46^{b}	50.45±7.60^{b}	17.70±0.53^{b}	7.21±0.05^{a}	5.73±0.09^{b}	94.70±0.14^{b}
BMFK	35.50±2.58^{f}	6.95±0.88^{c}	28.54±3.47^{d}	12.95±1.23^{c}	6.00±0.35^{b}	5.83±0.04^{a}	94.75±0.14^{b}
BMFL	61.70±0.53^{b}	13.33±0.12^{a}	48.37±0.41^{b}	20.33±0.12^{a}	7.00±0.24^{a}	5.93±0.00^{a}	94.85±0.00^{b}
BMFM	68.58±7.12	13.09±0.00^{a}	55.50±0.24^{a}	20.00±0.11^{a}	6.91±0.12^{a}	5.87±0.28^{a}	94.70±0.07^{b}
BMFN	49.95±0.53^{e}	11.92±1.76^{a}	30.04±2.53^{c}	18.50±2.47^{b}	6.58±0.70^{a}	6.06±0.09^{a}	95.02±0.03^{a}
BMFO	41.96±4.29^{e}	14.54±0.53^{a}	26.66±1.18^{d}	21.40±0.82^{a}	6.87±0.28^{a}	6.13±0.19^{a}	94.90±0.00^{b}

Mean values±standard deviations with different alphabetical superscripts in the same row are significantly different at $p \leq 0.05$.

Key: Samples BMFA through Sample BMFO: Boiled mucuna flour A to Z

stability due to processing effects and matrix interactions[27]. The observed decline in final viscosity with increasing sodium bicarbonate and oil levels, particularly in samples BMFD and BMFF, suggests disruption of gel formation and a weakened starch network due to protein interference during retrogradation. These lower viscosity values, when compared to those of wheat-plantain-tigernut blends[27], imply limited applicability of these flours in food systems that require high-viscosity or strong gel-forming properties.

Setback viscosity: Setback viscosity values ranged from 6.21 to 7.21 RVU, with no significant differences (p>0.05) observed among treatments. Sample BMFB recorded the highest value. The generally low setback viscosity suggests minimal starch retrogradation and reduced syneresis during cooling, characteristics that may enhance storage and textural stability in processed food systems[28].

Pasting time: Pasting time ranged between 5.73 and 6.13 min, representing the duration required to achieve peak viscosity. These findings align with those of Mounsey *et al.*[29], who reported values between 5.01 and 6.30 min for germinated tiger nut flour. Sample BMFJ exhibited the shortest pasting time (5.73 min), similar to raw *Mucuna* flour, suggesting efficient gelatinization possibly due to optimized interactions among the added oil and alkali components.

Pasting temperature: Pasting temperature ranged from 94.12-95.05°C, indicating a high energy requirement for gelatinization. These temperatures exceed those typically observed for conventional wheat flours and are consistent with values reported for modified legume starches[16]. The elevated pasting temperature likely reflects the compact starch granule structure of *Mucuna utilis* and the inhibitory effects of oil and sodium bicarbonate on starch gelatinization. Consequently, such flours may be less suitable for formulations requiring low energy input or rapid cooking.

CONCLUSION

This study revealed that the incorporation of sodium bicarbonate and vegetable oil significantly influenced the functional and pasting characteristics of boiled *Mucuna utilis* flour. Increasing levels of these additives resulted in decreased water and oil absorption capacities, bulk density, and swelling index, while improving emulsion capacity-indicating potential applicability in the formulation of emulsified and protein-enriched food products. The pasting behavior exhibited reduced peak and final viscosities alongside elevated pasting temperatures, suggesting diminished gel strength but enhanced resistance to retrogradation. Among the samples, BMFD demonstrated the most desirable properties, exhibiting the highest water absorption capacity (1.93 g/g) and an optimal balance between viscosity and stability, making it suitable for protein-rich formulations such as soups, sauces and breakfast cereals. Overall, treated *Mucuna utilis* flour appears suitable for low-viscosity applications and may be effectively combined with high-viscosity flours in baked or extruded products to enhance nutritional quality without compromising texture. Future research should focus on evaluating the sensory characteristics, storage stability and nutrient bioavailability of food products incorporating treated *Mucuna utilis* flour, particularly in cereal-based systems.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the invaluable technical assistance and support provided by the Head of the Department of Food Science and Technology, Madonna University, Nigeria, Enugu State, for granting access to the laboratory facilities. The authors also extend their sincere appreciation to the management of the State University of Medical and Applied Sciences, Enugu State, for their support and cooperation.

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