

Characterization of Functional, Pasting, and Microstructural Properties of Mung Bean Starch

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Abstract

Mung bean starch, a promising but underutilized ingredient, has the potential for wider application in the food industry. This study aimed to characterize its functional, pasting, and microstructural properties to provide a scientific basis for its enhanced use. Starch was isolated from dehulled mung beans, and its properties were analysed using standard methods. The starch exhibited high dispersibility (84.3%), swelling power (9.66 g/g), bulk density (0.94 g/ml), water absorption capacity (2.25 g/g), and oil absorption capacity (3.09 g/g). The values of peak viscosity, trough, breakdown viscosity, final viscosity, setback viscosity, peak time and pasting temperature were 7946 cP, 4382 cP, 3564 cP, 5044 cP, 662.5 cP, 4.17 min and 75.98 °C, respectively. The starch displayed a Type-C X-ray diffraction pattern, typical of legume starches. Scanning electron microscopy revealed irregularly shaped, oval, and kidney-shaped granules with a wide size distribution (0.7–52.2 µm). The prevalence of small granules suggests a strong affinity for water, potentially increasing yields in starch-based products. The unique combination of moderate thermal/shear stability, and microstructural characteristics makes mung bean starch a valuable ingredient for improving textural properties and enhancing yield in various food formulations, highlighting its potential for industrial applications.

Keywords:

Food applications, functional attributes, mung bean, pasting characteristics, starch granules

Introduction

Mung bean (*Vigna radiata* L.), a legume native to Asia, is cultivated extensively in Southeast Asia, Australia, New Zealand, and Africa (Yang et al., 2008). Its nutritional profile aligns with other legumes, comprising approximately 24% protein, 1% fat, 63% carbohydrates, and 16% dietary fiber (Jiang et al., 2015). Rich in vitamins, minerals, and essential amino acids, mung beans are consumed as cooked beans or sprouts (Li et al., 2011a; Li et al 2011b). Mung bean sprouts, valued for their affordability and nutritional benefits, are commonly eaten raw or lightly cooked in salads and sandwiches (Hou et al., 2019). Mung bean contains an appreciable quantity of starch.

Starch, a key energy reserve in plants like cereals, legumes, roots, and tubers, supplies 70–80% of global dietary calories. Beyond nutrition, starches enhance food texture and functionality through gelling, thickening, adhesion, moisture retention, stabilization, and texturization (Horstmann et al., 2017). Mung bean starch, primarily used in noodle production, is characterized by limited swelling, and a propensity for retrogradation (Dahiya et al., 2016; Mi et al., 2021). Its high viscosity makes it a valuable ingredient in food processing (Tarahi, 2025). Compared to cereal starches, legume starches exhibit greater viscosity due to enhanced resistance to swelling and granule rupture (Zhang et

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al., 2019; Nguetcho et al., 2021). Variations in starch properties arise from differences in source materials, affecting granule size, morphology, and physicochemical characteristics (Molenda et al., 2006; Alcázar-Alay & Meireles, 2015; Park et al., 2024). Pasting, and gelling behaviours are critical to mung bean starch functionality (Gunaratne et al., 2017).

Legume starches, including mung bean starch, are essential in global noodle production (Lii & Chang, 1981; Agvaandorj et al., 2025). Despite its potential, mung bean starch remains underutilized in food manufacturing (Gunaratne et al., 2017). It exhibits high intrinsic viscosity (Mengting et al., 2017; Agvaandorj et al., 2025). The distinct gelling mechanism of mung bean starch imparts unique textural qualities (Hongsprabhas, 2007; Li et al., 2010). Detailed characterization of its microstructure and functional properties can elucidate the relationship between molecular structure and product performance (Dahiya et al., 2015; Zhang et al., 2019; Mi et al., 2021; Agvaandorj et al., 2025). Additionally, mung bean starch may serve as a low glycemic index carbohydrate source (Hongsprabhas, 2007; Agvaandorj et al., 2025). This study aimed to isolate mung bean starch and assess its functional, pasting, and microstructural properties to support its broader application in food systems.

Materials and Methods

Mung bean samples were procured from local markets in Enugu, Nigeria. Analytical-grade reagents and equipment, including a Rapid Visco-Analyzer (RVA), weighing balance, thermometer, centrifuge, and milling machine, were sourced from the Department of Food Science and Technology, Federal University of Agriculture, Abeokuta, Nigeria.

Bung bean starch isolation

Starch was extracted using the method described by Abdel-Rahman et al. (2008). Mung beans were soaked in water for 16 hours, dehulled, and ground with an equal volume of fresh water using a Waring blender (Waring Commercial, USA; model 7011HBC/7012G). The slurry was filtered through muslin cloth and allowed to sediment for 12 hours. The supernatant was decanted, and the starch sediment was washed five times with distilled water. The starch was dried in a cabinet dryer (Serial No 3114; LEEC Limited, Nottingham, UK) at 60 °C for 12 hours to approximately 10% moisture content, milled using a hammer mill, and stored in the refrigerator until analysis.

Determination of functional properties of Mung bean starch

Bulk density

A 10 g starch sample was placed in a 50 mL graduated cylinder, gently tapped until a constant volume was achieved, and bulk density was calculated as weight per volume (Waring & Kinsella, 1976).

Dispersibility

Following Kulkarni et al. (1991), 10 g of starch was mixed with distilled water to a 100 mL volume, stirred vigorously, and allowed to settle for 3 hours. The volume of settled particles was subtracted from 100 to calculate dispersibility as a percentage.

Wettability

One gram of starch was added to 50 mL of water, and the time required for the last starch particle to be absorbed by the liquid was recorded (Jóźwiak et al., 2017).

Gelatinization temperature

A 10% starch suspension was heated in a boiling water bath with continuous stirring, and the temperature at which gelatinization was observed after 30 seconds was recorded (Onwuka, 2005).

Water and oil absorption capacity

One gram of starch was mixed with 10 mL of distilled water in a centrifuge tube, centrifuged at 3500 rpm for 15 minutes, and the supernatant was discarded. The weight gain represented water absorption capacity. For oil absorption, the starch was mixed with 10 mL of oil, allowed to stand for 30 minutes, and centrifuged at 5000 rpm for 30 minutes. The absorbed oil was calculated by subtracting the free oil volume, converted to grams using oil density (Onwuka, 2005).

Swelling power and solubility

Using the method of Ashri et al. (2014), a 1% starch suspension was heated at 100 °C for 30 minutes in a water bath (Model BKS-350-030; Gallenkamp, London, UK), cooled, and centrifuged at 3000 rpm for 15 minutes. The supernatant was evaporated at 110 °C overnight to determine solubility, while the swollen sediment was weighed to calculate swelling power using the equation provided by Ashri et al. (2014).

Colour

Starch colour was analyzed using a colorimeter (PCE-XXM 30 Color Meter, PCE Instruments, Meschede, Germany), with diffuse lighting, a 0° viewing angle,

and an 8 mm port, calibrated with a standard white plate. Results were recorded from the instrument's digital display (Ashri et al., 2014).

Determination of pasting properties of Mung bean starch

Pasting properties were assessed using a Rapid Visco Analyser (RVA) (model RVA 3D+; Network Scientific, 5Australia). A 3.5 g starch sample (14% moisture basis) was mixed with 25 mL of distilled water in a test canister, heated from 50 to 95 °C with a 2-minute hold, and cooled back to 50 °C with a 2-minute hold at a constant rate of 11.25 °C/min. Parameters including peak viscosity, trough, breakdown, final viscosity, setback, peak time, and pasting temperature were recorded using Thermocline software (Falade & Okafor, 2015).

Scanning electron microscopy (SEM)

Starch granules were mounted on epoxy bars, fractured after immersion in liquid nitrogen, gold-coated, and examined under SEM (JEOL JSM-6390LV, JEOL Inc., Massachusetts, USA) at 2 kV to assess surface and internal morphology. Micrographs were captured to aid the explanation of the result (Chen et al., 2006).

X-ray diffraction

The crystalline structure was analyzed using an ADX2700 SSC X-ray diffractometer at 40 kV and 30 mA with a chart speed of 20 mm/min. Diffraction patterns were compared to standard A, B, and C starch types to determine crystallinity, and interplanar spacing at intensity peaks was calculated (Hoover et al., 1997).

Statistical analysis

All analyses were conducted in triplicate (n=3), and the results were expressed as mean values with $\pm$ standard deviation using MS Excel version 11.

Results and Discussions

Functional properties of Mung bean starch

The functional properties are presented in Table 1. The starch exhibited a high bulk density of 0.94 g/mL, facilitating efficient packaging, cost reduction, and enhanced thickening in food systems (Udensi & Okaka, 2000; Mohamed et al., 2009; Adegoke et al., 2024). Water absorption capacity (WAC) and oil absorption capacity (OAC) were 2.25 g/g and 3.09 g/g, respectively, indicating the starch's potential to enhance product bulk, consistency, and moisture retention. These properties also improve texture,

mouthfeel, flavour retention, and fat binding in applications like baked goods and meat analogues (Adebowale et al., 2005; Butt & Batool, 2010; Adebowale et al., 2011; Kiosseoglou & Paraskevopoulou, 2011). Protein's hydrophilic and hydrophobic interactions influence these capacities. Dispersibility was 84.3%, reflecting excellent water reconstitution, which is advantageous for food applications (Adebowale et al., 2011; Kulkarni et al., 1991).

Gelatinization and retrogradation behaviours are linked to water interactions, supporting the starch's functionality. Swelling power at 100 °C was 9.66 g/g, influenced by the amylose-to-amylopectin ratio and molecular structure, including branching and molecular weight (Ratnayake et al., 2002; Cornejo-Ramirez et al., 2018). The high swelling power observed in mung bean starch is attributed to the high branch density of amylopectin, which facilitates water absorption into the granule matrix and promotes granule expansion during heating (Cornejo-Ramirez et al., 2018). The branched structure of amylopectin creates a more open network that readily absorbs water, thereby increasing the swelling capacity compared to starches with lower amylopectin branching (Nguetcho et al., 2021). Wettability, measured as the time for complete wetting, was 0.93 minutes, indicating strong water affinity, critical for industrial processes like coating and lubrication (Silva et al., 2017).

Emulsion capacity, linked to protein adsorption at the oil-water interface, was 1.84 mL/g, likely due to low protein content in the starch (Yi-shen et al., 2018). Although starch itself is hydrophilic and typically has low protein content, the observed emulsion capacity reflects the ability of starch granules to stabilize oil-water interfaces through their surface properties (Alcázar-Alay & Meireles, 2015). The limited emulsion capacity compared to protein-rich legume materials is expected, as starch granules lack the amphipathic nature of proteins (Nguetcho et al., 2021). However, the hydroxyl groups on the starch surface can provide some interfacial activity, particularly when granules are partially gelatinized or disrupted during emulsification (Yi-shen et al., 2018). This property is relevant for applications where starch serves as a co-stabilizer in emulsified food systems (Tarahi et al., 2025).

Gelatinization temperatures were recorded as onset (63.00 °C), peak (70.75 °C), and conclusion (78.50 °C), aligning with Li et al. (2015). Higher gelatinization temperatures suggest the presence of

stable crystallites within mung bean starch granules, requiring more energy to initiate gelatinization (Hermansson & Svegmarm, 1996; Abdel-Rahman et al., 2008). These temperatures indicate the minimum heat needed for viscosity increase during processing (Kaur et al., 2009).

Table 1: Functional properties of Mung bean starch

Functional properties	Values
Bulk Density (g/ml)	0.96±0.04
Dispersibility (%)	84.3±0.35
Water Absorption Capacity (g/g)	2.25±0.00
Oil Absorption Capacity (g/g)	3.09±0.60
Swelling Power (g/g)	9.66±0.60
Solubility (%)	16.95±1.48
Wettability (min)	0.93±0.71
Emulsion Capacity (ml/g)	1.84±0.92
Gelatinization Temperature (T°C)	(T _o) 63.00±1.41 (T _p) 70.75±1.79 (T _c) 78.50±2.12

Mean ± standard deviation

Colour characteristics of Mung bean starch

The colour of the mung bean starch was evaluated using both the Hunter's Lab and CIELAB colour spaces. The Hunter Lab L value was 72.53, while the CIELAB L* value was 77.64, indicating a bright, light-coloured starch. The whiteness index, calculated from the Hunter Lab values, was 72.39%, demonstrating high whiteness and purity of the starch. The low a and b values (Hunter Lab: a=1.12, b=3.54; CIELAB: a*=1.18, b*=3.85) indicate minimal redness and yellowness, confirming the neutral, white appearance of the isolated starch. This high whiteness is advantageous for food applications, as it allows for better colour control in formulated products and does not impart undesirable colour to finished goods. The little difference between Hunter Lab and CIELAB measurements validates the consistency of the colour analysis. The bright, neutral colour of mung bean starch makes it suitable for applications in white or light-coloured food products such as noodles, bakery items, and sauces (Table 2).

Table 2: Colour characteristics of Mung bean starch

Parameters	Values	Whiteness (%)
Hunter Lab		
L	72.53±0.69	72.39±0.83
a	1.12±0.00	
b	3.54±0.28	
CIELAB		
L*	77.64±0.59	77.28±0.58
a*	1.18±0.00	
b*	3.85±0.21	

Mean ± standard deviation, *L=Light/Dark *a=Red/green
*b=Yellow/blue

Pasting properties of Mung bean starch

Pasting properties are detailed in Table 3. Heating starch suspensions induces a significant viscosity increase, with peak viscosity reflecting water-holding capacity and correlating with product quality (Adebowale et al., 2008). High breakdown viscosity indicates low resistance to heat and shear stress during cooking (Adebowale et al., 2005). Final viscosity, indicative of gel formation post-cooling, was high due to amylose aggregation (Kaur et al., 2009). Setback viscosity, associated with retrogradation, may lead to syneresis during freeze-thaw cycles (Adebowale et al., 2011). The setback viscosity was 662.5 cP, which is associated with starch paste retrogradation during cooling and storage. This relatively moderate setback viscosity suggests that mung bean starch exhibits controlled retrogradation behaviour, which is favourable for maintaining product texture and preventing excessive syneresis during freeze-thaw cycles (Adebowale et al., 2011). However, products formulated with mung bean starch may experience some textural changes during storage, requiring appropriate packaging and storage conditions to maintain shelf-life quality. This is particularly important for frozen or refrigerated food products where freeze-thaw cycles are anticipated. Pasting temperature reflects the minimum cooking temperature, impacting energy costs and formulation stability (Adebowale et al., 2005). As a Type-C starch, mung bean starch exhibits limited granule swelling and stability during cooking, making it suitable for bakery products like cookies and cakes (Li et al., 2011b; Ratnawati et al., 2019). Pasting behaviour is influenced

by granule size, amylose/amylopectin ratio, and processing conditions (Shimelis et al., 2006).

Table 3: Pasting properties of mung bean starch

Pasting properties	Values
Peak Viscosity (cP)	7946±1.41
Trough Viscosity (cP)	4382±18.38
Breakdown Viscosity (cP)	3564±19.80
Final Viscosity (cP)	5044.5±109.60
Setback Viscosity (cP)	662.5±127.99
Peak Time (min)	4.17±0.05
Pasting Temperature (T °C)	75.98±0.035

Mean ± standard deviation

Microstructure of Mung Bean Starch

SEM analysis revealed diverse granule morphologies, ranging from irregular to oval and kidney-shaped, with sizes from 0.7 to 52.2 µm (Figure 1), consistent with Horstmann et al. (2017). Granule surfaces appeared smooth without fissures. Small granules exhibit higher

water affinity and less ordered polysaccharide chains, influencing textural properties in food systems (Chiotelli & Meste, 2002; Hongsprabhas, 2007). The Type-C crystallinity supports the starch's gelatinization properties (Singh et al., 2003; Lindeboom, 2004; Cornejo-Ramirez et al., 2018).

X-Ray Diffraction Pattern of Mung Bean Starch

The starch exhibited a Type-C X-ray diffraction pattern (Figure 2), characterized by five strong intensity peaks at 2-Theta values of 15.49, 17.35, 18.31, 23.31, and 26.93, with a maximum intensity of 211. The interplanar spacing values were calculated as 5.715, 5.108, 4.842, 3.814, and 3.308 Å (Table 4). The Type-C pattern is the characteristic of legume starches and indicates a mixture of crystalline polymorphs (Alcázar-Alay & Meireles, 2015). The strong peaks at 15.49 and 17.35 degrees are consistent with the Type-C classification. The Type-C crystallinity observed

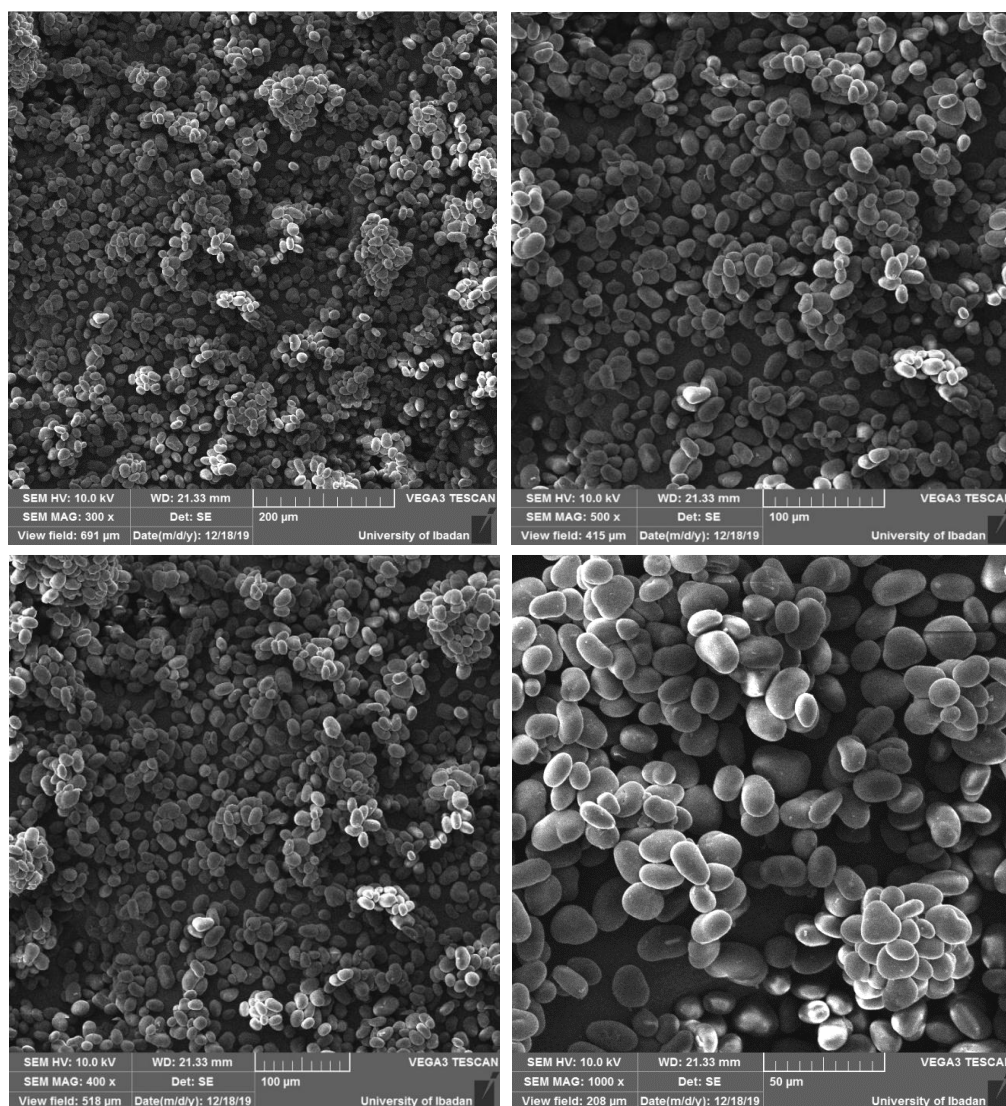


Figure 1: Scanning electron micrographs of mung bean starch with magnification 300x, 400x, 500x and 1000x from left to right

correlates with the thermal stability and controlled gelatinization behaviour noted in the pasting properties, where the starch exhibits resistance to granule swelling and rupture during cooking (Cornejo-Ramirez et al., 2018). This crystalline structure is

directly linked to the microstructural observations from SEM, where the diverse granule morphologies and size distribution reflect the underlying crystalline organization within individual granules (Hoover et al., 1997).

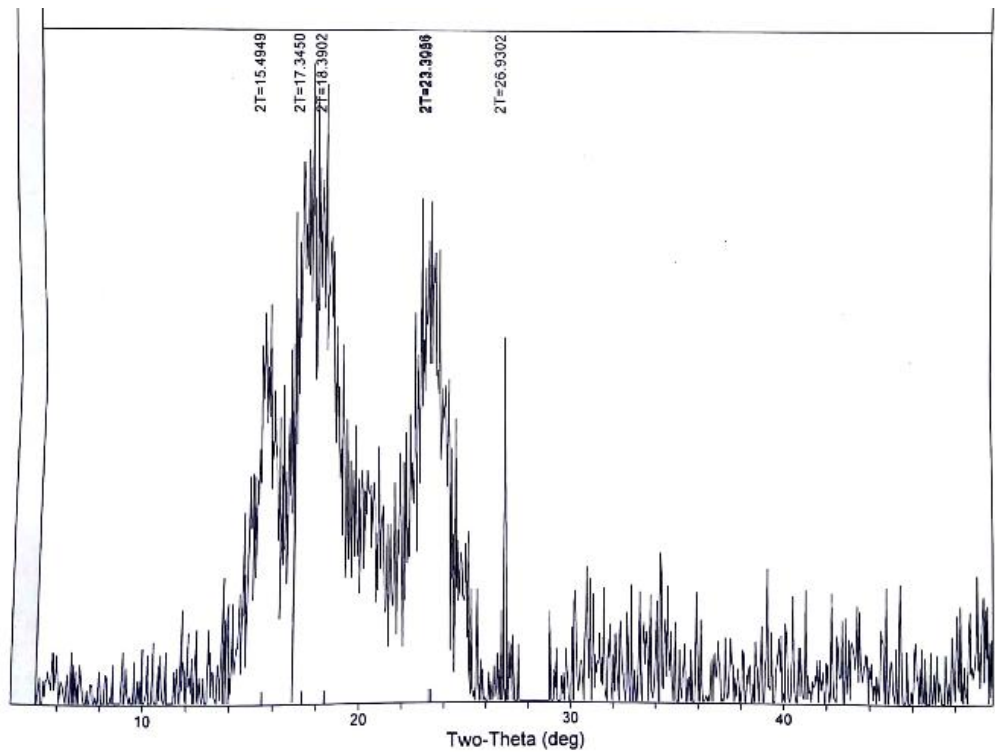


Figure 2: X-Ray Diffraction Pattern of mung bean starch

Table 4: X-ray diffraction intensities of the major peaks of mung bean starch

Two-Theta Values	Interplanar Spacing (d value (Å))
15.4949	5.715
17.3456	5.108
18.3092	4.842
23.3056	3.814
26.9302	3.308

*I_{max} = 211, moisture content = 12.30%

Conclusion

Mung bean starch exhibited distinct functional, pasting, and microstructural properties, differentiating it from other legume starches. The combination of high bulk density, good water and oil absorption capacities, and swelling power makes it valuable for enhancing texture, consistency, and moisture retention in food formulations. The small granules enhance water affinity, increasing yields in starch-based products. These comprehensive characterization findings provide a scientific foundation for optimizing mung bean starch utilization in industrial food production and for developing new food applications that leverage its unique physicochemical properties.

References

Abdel-Rahman, E. S. A., El-Fishawy, F. A., El-Geddawy, M. A., Kurz, T., & El-Rify, M. N. (2008). Isolation and physicochemical characterization of mung bean starches. *International Journal of Food Engineering*, 4(1), 1–12. <https://doi.org/10.2202/1556-3758.1293>

Adebowale, A. A., Sanni, L. O., & Awonorin, S. O. (2005). Effect of texture modifiers on the physicochemical and sensory properties of dried fufu. *Food Science and Technology International*, 11(5), 373–382. <https://doi.org/10.1177/1082013205058558>

- Adebowale, A. A., Sanni, L. O., & Fadahunsi, E. L. (2011). Functional and pasting properties of cassava-sweetpotato starch blends. *African Journal of Root and Tuber Crops*, 9(1), 6–10.
- Adebowale, A. A., Sanni, L. O., & Onitilo, M. O. (2008). Chemical composition and pasting properties of tapioca grits from different cassava varieties and roasting methods. *African Journal of Food Science*, 2, 77–82.
- Adegoke, A., Oyedara, J., Hussein, J., Omohimi, C., Omidiran, A., John, E., Kajihansa, O., Adekoyeni, O., Adebowale, A., & Oke, M. (2024). Thermal, functional, and pasting characteristics of flours from selected millet varieties in Nigeria. *Nigerian Journal of Nutritional Sciences*, 45(1), 12–21.
- Agvaandorj, A., Li, Y., & No, J. (2025). Effects of structural changes in cross-linked mung bean starch on freeze–thaw properties and in vitro digestibility. *Foods*, 14(4), 689. <https://doi.org/10.3390/foods14040689>
- Alcázar-Alay, S.C & Meireles, A.A. (2015). Physicochemical properties, modifications and applications of starches from different botanical sources. *Food Science and Technology* (Campinas), 35(2):215-236. <https://doi.org/10.1590/1678-457X.6749>
- Ashri, A., Yusof, M. S. M., Jamil, M. S., Abdullah, A., Yusoff, S. F. M., & Nasir, M. M. (2014). Physicochemical characterization of starch extracted from Malaysian wild yam (*Dioscorea hispida* Dennst.). *Emirates Journal of Food and Agriculture*, 26(8), 652–658. <https://doi.org/10.9755/ejfa.v26i8.17098>
- Butt, M. S., & Batool, R. (2010). Nutritional and functional properties of some promising legume protein isolates. *Pakistan Journal of Nutrition*, 9(4), 373–379. <https://doi.org/10.3923/pjn.2010.373.379>
- Chen, P., Yu, L., Chen, L., & Li, X. (2006). Morphology and microstructure of maize starches with different amylose/amylopectin content. *Starch/Staerke*, 58(12), 611–615. <https://doi.org/10.1002/star.200500529>
- Chiotelli, E., & Le Meste, M. (2002). Effect of small and large wheat starch granules on thermomechanical behavior of starch. *Cereal Chemistry*, 79(2), 286–293. <https://doi.org/10.1094/CCHEM.2002.79.2.286>
- Cornejo-Ramírez, O. M., Del Toro-Sánchez, C. L., & Cinco-Moroyoqui, F. J. (2018). The structural characteristics of starches and their functional properties. *CYTA – Journal of Food*, 16(1), 1003–1017. <https://doi.org/10.1080/19476337.2018.1518343>
- Dahiya, P. K., Linnemann, A. R., Van Boekel, M. A., Khetarpaul, N., Grewal, R. B., & Nout, M. J. (2015). Mung bean: Technological and nutritional potential. *Critical Reviews in Food Science and Nutrition*, 55(5), 670–688. <https://doi.org/10.1080/10408398.2012.671202>
- Falade, K. O., & Okafor, C. A. (2015). Physical, functional, and pasting properties of flours from corms of two cocoyam (*Colocasia esculenta* and *Xanthosoma sagittifolium*) cultivars. *Journal of Food Science and Technology*, 52(6), 3440–3448. <https://doi.org/10.1007/s13197-014-1368-9>
- Gunaratne, A., Gan, R., Wu, K., Kong, X., Collado, L., Arachchi, L., & Corke, H. (2018). Physicochemical properties of mung bean starches isolated from four varieties grown in Sri Lanka. *Starch/Staerke*, 70(3-4), 1700129. <https://doi.org/10.1002/star.201700129>
- Hermansson, A.-M., & Svegmarm, K. (1996). Developments in the understanding of starch functionality. *Trends in Food Science and Technology*, 7(10), 345–353. [https://doi.org/10.1016/S0924-2244\(96\)10043-9](https://doi.org/10.1016/S0924-2244(96)10043-9)
- Hongsprabhas, P. (2007). On the gelation of mung bean starch and its composites. *International Journal of Food Science and Technology*, 42(6), 658–668. <https://doi.org/10.1111/j.1365-2621.2006.01448.x>
- Hoover, R., Li, Y. X., Hynes, G., & Senanayake, N. (1997). Physicochemical characterization of mung bean starch. *Food Hydrocolloids*, 11(4), 401–408. [https://doi.org/10.1016/S0268-005X\(97\)80037-9](https://doi.org/10.1016/S0268-005X(97)80037-9)
- Horstmann, S. W., Lynch, K. M., & Arendt, E. K. (2017). Starch characteristics linked to gluten-free products. *Foods*, 6(4), 29. <https://doi.org/10.3390/foods6040029>
- Hou D, Yousaf L, Xue Y, Hu J, Wu J, Hu X, Feng N. & Shen Q. (2019). Mung Bean (*Vigna radiata* L.): Bioactive Polyphenols, Polysaccharides, Peptides, and Health Benefits. *Nutrients*. 31;11(6):1238. <https://doi.org/10.3390/nu11061238>

- Jiang, H., Zhang, Z., Tian, X., & Li, W. (2015). The impact of germination on the nutritional and physicochemical properties of mung bean starch and flour. *Acta Agrestia Sinica*, 23(6), 1211–1217.
- Józwiak, T., Filipczak, G., & Piekarska, A. (2017). The effect of starch wettability on the properties of moulding sands with starch-based binders. *Archives of Foundry Engineering*, 17(4), 61–65. <https://doi.org/10.1515/afe-2017-0129>
- Kiosseoglou, V., & Paraskevopoulou, A. (2011). Functional and physicochemical properties of pulse proteins. In B. K. Tiwari, A. Gowen, & B. McKenna (Eds.), *Pulse foods: Processing, quality and nutraceutical applications* (pp. 57–90). Elsevier Inc.
- Kulkarni, K. D., Kulkarni, D. N., & Ingle, U. M. (1991). Sorghum malt-based weaning food formulations: Preparation, functional properties, and nutritive value. *Food and Nutrition Bulletin*, 13(4), 322–327. <https://doi.org/10.1177/156482659101300413>
- Li, S. L., Ward, R., & Gao, Q. Y. (2011a). Effect of heat–moisture treatment on the formation and physicochemical properties of resistant starch from mung bean (*Phaseolus radiatus*) starch. *Food Hydrocolloids*, 25(7), 1702–1709. <https://doi.org/10.1016/j.foodhyd.2011.03.013>
- Li, W. H., Guo, H. M., Wang, P., Tian, X., Zhang, W., Saleh, A. S. M., Zheng, J., Ouyang, S., Luo, Q., & Zhang, G. (2015). Physicochemical characteristics of high pressure gelatinized mung bean starch during recrystallization. *Carbohydrate Polymers*, 131, 432–438. <https://doi.org/10.1016/j.carbpol.2015.05.076>
- Li, W. H., Shu, C., Zhang, P. L., & Shen, Q. (2011b). Properties of starch separated from ten mung bean varieties and seeds processing characteristics. *Food and Bioprocess Technology*, 4(5), 814–821. <https://doi.org/10.1007/s11947-009-0204-y>
- Lii, C. Y., & Chang, S. M. (1981). Characterization of red bean (*Phaseolus radiatus* var. aurea) starch and its noodle quality. *Journal of Food Science*, 46(1), 78–81. <https://doi.org/10.1111/j.1365-2621.1981.tb14534.x>
- Lindeboom, N., Chang, P. R., & Tyler, R. T. (2004). Analytical, biochemical, and physicochemical aspects of granule size, with emphasis on small granule starches: A review. *Starch/Staerke*, 56(3-4), 89–99. <https://doi.org/10.1002/star.200300218>
- Mengting M., Wang, Y. WangM., Jane, J. & Du,S. (2017). Physicochemical properties and in vitro digestibility of legume starches, *Food Hydrocolloids*, 63,249-255
- Mi, G., Wang, T., Li, J. R., Li, X. P.& Xie, J. (2021). Physicochemical properties and microstructure of mung bean starch noodles fortified with sea bass (*Lateolabrax japonicus*) actomyosin. *International Food Research Journal*, 28(4): 726 – 736.
- Mohamed, T. K., Zhu, K., Issoufou, A., Fatmata, T., & Zhou, H. (2009). Functionality, in vitro digestibility, and physicochemical properties of two varieties of defatted foxtail millet protein concentrates. *International Journal of Molecular Sciences*, 10(12), 5224–5238. <https://doi.org/10.3390/ijms10125224>
- Molenda, M., Montagnac, G., & O'Brien, M. M. (2006). Protein and starch characteristics of a diverse collection of edible beans (*Phaseolus vulgaris* L.). *Journal of Agricultural and Food Chemistry*, 54(21), 8044–8051. <https://doi.org/10.1021/jf061198h>
- Nguetcho V.S.T., Bouba, A.A. & Yanou, N.N. (2021). Technological potential of under-utilized starches from eight varieties of legumes grown in Cameroon. *Braz. J. Biol.* 81(1), Jan-Feb 2021 <https://doi.org/10.1590/1519-6984.195234>
- Onwuka, G. I. (2005). *Food analysis and instrumentation: Theory and practice*. Naphthali Prints.
- Park, H. J., Cho, D. H., Chung, H. J., & Lim, S. T. (2024). Enhanced gelling property and freeze-thaw stability of potato, tapioca, and corn starches modified by mild heating in aqueous ethanol solution. *Journal of the Science of Food and Agriculture*, 104(14), 7228–7237. <https://doi.org/10.1002/jsfa.13328>
- Ratnawati, L., Desnilasari, D., & Surahman, D. N. (2019). Evaluation of physicochemical, functional, and pasting properties of soybean, mung bean, and red kidney bean flour as ingredients in biscuit. *IOP Conference Series: Earth and Environmental Science*, 251, 012026. <https://doi.org/10.1088/1755-1315/251/1/012026>
- Ratnayake, W. S., Hoover, R., & Warkentin, T. (2002). Pea starch: Composition, structure, and properties-A review. *Starch/Staerke*, 54(6),

- 217–234. [https://doi.org/10.1002/1521-379X\(200206\)54:6](https://doi.org/10.1002/1521-379X(200206)54:6)
- Shimelis, E., Meaza, M., & Rakshit, S. (2006). Physico-chemical properties, pasting behavior and functional characteristics of flours and starches from improved bean (*Phaseolus vulgaris* L.) varieties grown in East Africa. *CIGR E-journal*, *VIII*, 1–18.
- Silva, G., Correia, B., Cunha, A., Santos, B., & Lima, A. (2017). Water rejection for oil recovery by using a reservoir. *International Journal of Multiphysics*, *11*(1), 83–96. <https://doi.org/10.21152/1750-9548.11.1.83>
- Singh, N., Singh, J., Kaur, L., Sodhi, N. S., & Gill, B. S. (2003). Morphological, thermal, and rheological properties of starches from different botanical sources. *Food Chemistry*, *81*(2), 219–231. [https://doi.org/10.1016/S0308-8146\(02\)00416-8](https://doi.org/10.1016/S0308-8146(02)00416-8)
- Tarahi, M., Partovi, G.A. & Hedayat, S. (2025). Mung bean as an emerging source of starch: A review on its isolation, structure, functionality, modification, and application. *Food Chemistry*, 497, 147033. <https://doi.org/10.1016/j.foodchem.2025.147033>
- Udensi, E. A., & Okaka, J. C. (2000). Predicting the effect of blanching, drying temperature, and particle size profile on the dispersibility of cowpea flour. *Nigerian Food Journal*, *18*, 25–31.
- Yang, R., Li, Y., & Wang, Q. (2008). A review of the research and development of mung bean (*Vigna radiata*). *Journal of the Chinese Cereals and Oils Association*, *23*(3), 223–226.
- Yi-shen, Z., Shuai, S., & Fitzgerald, R. (2018). Mung bean proteins and peptides: Nutritional, functional, and bioactive properties. *Food & Nutrition Research*, *62*. <https://doi.org/10.29219/fnr.v62.1294>
- Zhang, Z. S., Tian, X. L., Wang, P., Jiang, H., & Li, W. H. (2019). Compositional, morphological, and physicochemical properties of starches from red adzuki bean, chickpea, faba bean, and baiyue bean grown in China. *Food Science & Nutrition*, *7*(8), 2485–2494. <https://doi.org/10.1002/fsn3.1084>