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Proximate properties, tannin content and functional characteristics of selected pearl millet and finger millet varieties cultivated in Zimbabwe.

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Abstract

Pearl and finger millet grains are important climate-smart crops that are relatively underutilised in Zimbabwe. The objective of this study was to characterise the proximate, functional and tannin content of pearl (Okashana 1, PMV 2 and PMV 3) and finger millet (FMV 1 and FMV 2) varieties cultivated in Zimbabwe. Proximate analysis results were: moisture content 13.10 % (Okashana 1), 12.15 % (PMV 2), 13.43 % (PMV 3), 13.15 % (FMV 1) and 13.55 % (FMV 2); carbohydrate content was 65.57 % (Okashana 1), 69.23 % (PMV 2), 64.53 % (PMV 3), 72.57 % (FMV 1) and 69.91 % (FMV 2); crude protein of 9.81 % (Okashana 1), 7.29 % (PMV 2), 10.92 % (PMV 3), 5.98 % (FMV 1) and 9.14 % (FMV 2); crude fat content was 5.39 % (Okashana 1), 6.10 % (PMV 2), 5.97 % (PMV 3), 1.95 % (FMV 1) and 1.49 % (FMV 2); crude ash content of 2.93 % (Okashana 1), 2.13 % (PMV 2), 1.83 % (PMV 3), 2.95 % (FMV 1) and 2.36 % (FMV 2); and crude fibre content was 3.20% (Okashana 1), 3.10% (PMV 2), 3.30% (PMV 3), 3.40% (FMV 1) and 3.55% (FMV 2). The tannin content (catechin equivalent) of the grain varieties was 0.107 % (Okashana 1), 0.071 % (PMV 2), 0.020 % (PMV 3), 0.200 % (FMV 1) and 0.406 % (FMV 2). The functional properties results were: water absorption capacity 1.32 ml/g (Okashana 1), 1.21 ml/g (PMV 2), 1.26 ml/g (PMV 3), 1.34 ml/g (FMV 1) and 1.29 ml/g (FMV 2); oil absorption capacity 1.16 ml/g (Okashana 1), 1.35 ml/g (PMV 2), 1/17 ml/g (PMV 3), 1.17 ml/g (FMV 1) and 1.44 ml/g (FMV 2); and dispersibility of 73.33% (Okashana 1), 74.66 % (PMV 2), 75.33 % (PMV 3), 79.33 % (FMV 1) and 75.00 % (FMV 2). The millet varieties demonstrated potential to be utilized in developing food products that could help address food and nutritional security and the best varieties are PMV 3 and FMV 2.

Keywords: Food security, proximate composition, functional properties, underutilisation, droughts.

Background

Food security is defined as the state in which every person always has physical, social, and economic means to acquire adequate, safe, and nutritious food that meets their nutritional requirements and food choices for an active and healthy life (Chitondo, Chanda & Phiri, 2024). Food insecurity is largely felt by children, pregnant women, and low-income households (Food and Agriculture Organization [FAO], 2024; World Food Programme [WFP], 2024). Generally, food security has been difficult to achieve in Southern Africa as the agricultural environment is exposed to multifaceted stress such as heat stress, temperature increases and frequent droughts (Mutengwa, Mnkeni & Kondwakwenda, 2023).

In 2023, the effects of the El Nino phenomenon were felt worldwide and in the Southern African region, it was characterized by a temperature rise of 5 °C, subnormal rainfall (WFP, 2024), harvest loss and food insecurity (United Nations Office for the Coordination of Humanitarian Affairs [OCHA], 2024). Southern Africa's agricultural industry is majorly reliant on rainfall for farming thus making it prone to the negative effects of El Nino-induced below-average rainfall (Mutengwa *et al.,* 2023). The effects of the El Nino on harvest losses were forecasted to compromise farmers' livelihoods in year 2024, especially the subsistence farmers, resulting in them failing to cater to their basic needs (OCHA, 2024) and having minimal opportunities to generate income.

Maize is the staple and the most grown rain-fed cereal by smallholder farmers in Zimbabwe (Zimbabwe Vulnerability Assessment Committee [ZimVAC], 2020), as well as in other countries in Southern Africa. It requires at least 600 mm of evenly distributed rainfall to reach full maturity. Insufficient rainfall received during the 2023/2024 farming season has led to a decline in maize yield, thus leading to food insecurity. Therefore, there is an increasing need to promote the cultivation of drought-tolerant and underutilized cereals such as pearl and finger millets in low-rainfall areas.

Pearl millet (*Pennisetum glaucum*) is the third most grown cereal in Zimbabwe after maize and wheat (ZimVAC, 2020). Pearl millet can grow well in areas plagued by high temperatures, drought and high saline soils (Krishnan & Meera, 2018), compared to wheat and maize (Phiri *et al.,* 2019). Finger millet (*Eleusine coracana*) is the least grown millet in Zimbabwe (ZimVAC, 2020). Like pearl millet, finger millet grows well in semi-arid areas without much effect on production yield. Finger millet has been dubbed as one of the most nutritious cereals (Ambati & Sucharitha, 2019).

Pearl millet grains are used to make porridges, flatbreads, couscous, desserts, and alcoholic beverages such as opaque beer, mbeg, merissa, and non-alcoholic beverages namely: boa, mahewu, pombe and marewa in Africa and India (Adebiyi *et al.*, 2018). Previous studies have also shown that finger millets can be incorporated into the production of baked goods such as biscuits, bread and muffins.

Despite the historical and nutritional significance of Zimbabwe's indigenous pearl and finger millet varieties, a critical research gap exists as their proximate composition, functional properties, and tannin levels remain largely uncharacterized and unpublished. This oversight stems from a historical research bias favouring major staples like maize, which has left these climate-smart crops scientifically neglected. Recent agronomic studies explore their genetic yield potential; the fundamental quality traits of the grain itself have been overlooked. Consequently, the food industry lacks the empirical data needed for product development, nutritionists cannot quantify their precise dietary value, and the traditional knowledge held by rural communities remains scientifically unvalidated.

Furthermore, the Zimbabwean government has pushed for cultivation of small grains such as pearl and finger millet in semi-arid areas to curb the effects of erratic rainfall through the Pfumvudza (Zero tillage/Intwasa) initiative. This has the potential to further increase the availability of millet grains in the long term. Hence the study intends to complement the efforts of the Zimbabwean government to help increase food security within climate vulnerable communities.

Therefore, this study seeks to fill this void by systematically characterizing these properties, thereby providing the essential baseline data required to unlock the full nutritional, industrial, and food security potential of Zimbabwe's native millet landraces.

Methods

Raw materials

Four pearl millet varieties (PMV 1, PMV 2, PMV 3 and Okashana 1) and two finger millet varieties (FMV 1 and FMV 2) grown in Zimbabwe were acquired from Matopos ICRISAT. The millet varieties were cleaned, sorted and stored in airtight zip lock bags at 20°C.

Flour preparation

The pearl and finger millet grains were milled using a laboratory mill (Perten Instruments, Model 3310) and passed through a 180 µm mesh sieve to obtain uniform millet flour. The milled flours were packaged in zip-lock type polyethylene plastic bags and stored at room temperature.

Proximate composition

The moisture content, crude fat, crude protein and crude ash were determined using methods described by the Association of Official Analytical Chemist (AOAC, 2005). Total carbohydrate was calculated using the difference method (100 − % protein + % fat + % ash + % moisture)

Moisture content

The moisture content was determined using a method 925.10 outlined by Association of Official Analytical Chemist (AOAC, 2005). The crucibles were washed, dried for 60 seconds in an oven, cooled in a desiccator for 20 minutes and then weighed (W1). 10 g of the sample was put into the crucibles and then weighed again (W2). The samples were dried in the oven at 105°C for 3 hours, then allowed to cool in a desiccator, reweighed and oven dried again, this was repeated several times until constant weight was noted (W3).

% Moisture content = $(W_2 - W_3) / (W_2 - W_1)$
Where, W_1 = weight of the crucible
W_2 = weight of the crucible + sample before drying
W_3 = weight of the crucible + sample after drying

Crude fat

Crude fat of the samples was extracted following method 920.39 as stipulated by AOAC (2005). A clean filter paper free from any impurities was weighed (W_1). 1 g of the sample was placed on the filter paper, then gently folded and tied, the sample was weighed again (W_2). Crude fat was extracted from the sample using the Soxhlet method. Hexane was poured into a 500 ml round bottom flask until it reached a three-quarter mark. Then the flask was connected onto the Soxhlet extractor with a reflux condenser and placed on an electric mantle heater. The refluxing of the solvent indicated the start of the 6-hour extraction process. The condenser was then detached and disconnected; the fatless sample was collected and oven dried at 105ºC for 2 hours until a constant weight was reached. The weight of the fat (W_3) was calculated as the difference between the weight of the defatted sample before and after drying.

Crude Fat (%) = $(W_2 – W_{1)}$ / W x 100

Crude protein

Crude protein of the samples was determined using method 975.09 (AOAC, 2005). 0.105 g of the sample, 2 g of potassium sulfate and 0.05 g cupric sulfate were placed in a Kjeldahl flask. 2 ml of concentrated sulfuric acid was then added to each Kjeldahl flask and placed in a digestion unit and heated to prompt the start of digestion. The samples were acid-digested for 45 minutes and the hydrolysate was allowed to cool down before the addition of 10 ml of distilled water to it. 5 ml of boric acid and 20 ml of distilled water were mixed together in a 100 ml Erlenmeyer flask. The flask was connected to a digestion bulb on the condenser of the nitrogen distillation unit and the tip of the condenser was immersed into the Erlenmeyer flask with boric acid solution. Then 10 ml of the sodium hydroxide solution was placed in the distillation unit container and gradually added to the Kjedahl flask until the boric acid solution turned green. The green solution was then titrated against normalized hydrochloric solution until the green color disappeared. A few more drops of hydrochloric acid were added to the sample until it turned light-red salmon in colour. The amount and strength of normalized solution needed to titrate the sample was noted. The nitrogen and protein were calculated using the formulas below:

% Nitrogen= [(ml HCl (N HCl) (14.007) (100)]/ (mg sample weight)

% Crude protein= (% nitrogen) (6.25 correction factor)

Crude fibre

Crude fibre was determined using a method 962.09 outlined by AOAC (2005). 5 g of the sample was transferred into a 1 L conical flask. 100 ml of sulphuric acid (0.255 mol/L) was heated to boiling point and then added into the conical flask containing the sample. The contents were then boiled for 30 minutes, ensuring that the level of the acid was maintained by the addition of distilled water. After 30 minutes, the contents were then filtered through a muslin cloth held in a funnel. The residue was rinsed thoroughly until its washing was no longer acidic to litmus. The residue was then transferred into a conical flask. 100 ml of sodium hydroxide (0.313 mol/L) was then brought to a boil and then added into the conical flask containing the sample. The contents were then boiled for 30 minutes, ensuring that the level of the acid was maintained by the addition of distilled water. After 30 minutes, the contents were filtered through a muslin cloth held in the funnel. The residue was rinsed thoroughly until its washing was no longer alkali. The residue was then introduced into an already dried crucible and ashed at 600°C.

$$\text{Crude fibre\%} = \frac{\text{Final weight of crucible} - \text{initial weight of crucible}}{\text{Weight of sample}} \times 100$$

Crude ash

Method 923.03 outlined by AOAC (2005) was used to determine the crude ash of the samples. Firstly, a crucible was pre heated in the oven at 105 °C for 30 minutes, then cooled in the desiccator for an hour and its weight was noted (W_1). 1 g of the sample was put into the crucible thus giving it a new weight (W_2). The sample was then ashed in a muffle furnace at 55 °C for 3 hours until the sample turned whitish in colour. It was then cooled in a desiccator and its final weight was noted (W_3).

Ash (%) = $(W_2 - W_3) / (W_2 - W_1)$

Where,

W_1 = weight of the crucible

W_2 = weight of the crucible + sample before ashing

W_3 = weight of the crucible + sample after ashing

Carbohydrates

Total carbohydrate was calculated by difference as cited by Reddy, Shivakumara and Aneesha (2019) using the following formula:

Carbohydrates (%) = 100 – (% Moisture + % Ash + % Fat + % Protein + %Fibre)

Tannins

Condensed tannins were determined using the modified Vanillin-HCl in methanol method according to Price, Van Scoyoc and Butler (1978). 0.25 g of the sample was weighed into a 50 ml Erlenmeyer flask, and then 10 ml of 4 % HCI in methanol (v/v) was added and the content shaken for 20 min using Ratek Orbital Incubator. The sample was then centrifuged at 2060 ×g for 20 minutes and then 1 ml of the sample extract was mixed with 5 ml of Vanillin-HCI reagent. Then the absorbance was read at 500 nm using UV/VIS Spectrophotometer (model UV-1100, manufacturer Biobase) after 20 minutes. Sample blanks were prepared using 4% HCl in methanol, and catechin was employed as the reference standard. A standard curve was prepared using catechin at concentrations ranging from 5 to 100 µg/mL in 4% HCl in methanol. The standard equation (regression equation) for the catechin calibration curve used was:

$y=mx + c$

Where:

y: is the absorbance measured at 500 nm.

x: is the catechin concentration in µg/mL.

m: is the slope of the line (representing the sensitivity of the method).

c: is the y-intercept (ideally close to zero after blanking).

Tannin content in samples was expressed as % catechin equivalent using this calibration curve.

Water absorption capacity

The water absorption of the flour samples was determined using a method by Awuchi, Igwe and Echeta (2019), with minor modifications. Firstly, 2 g of the sample was mixed with 10 ml of distilled water for 5 minutes using a magnetic stirrer, and then centrifuged at 3500rpm for 30 minutes. The supernatant was then discarded, and the residue weighed. Water absorption capacity was calculated using the formula below:

Water Absorption Capacity (ml/g) = (Volume of water absorbed / Weight of the sample used)

$$\text{Water Absorption Capacity}\frac{\text{ml}}{\text{g}} = \text{Volume of water}\frac{\text{absorbed}}{\text{Weight}}\text{ofthe sample used}$$

Oil absorption capacity

Oil absorption capacity was determined using the method stipulated by Akume, Ariahu and Acham (2019). Firstly, 10 ml of oil was mixed with 1 g of the flour sample in a beaker and stirred using a magnetic stirrer for 3 minutes. Then the suspension was centrifuged at 3500 rpm for 30 minutes, and the supernatant was measured into a 10 ml granulated cylinder. The equation below was used to calculate oil absorption capacity:

Oil absorption capacity (ml/g) = (Volume of water absorbed / Weight of the sample used) x 100

Dispersibility

Dispersibility of the samples was determined by a method described by Olapade, Babalola and Aworh (2014). Firstly, 10 g of the flour sample was vigorously mixed with distilled water into a 100 ml measuring cylinder and then allowed to stand for 3 hours. The volume of settled particle was recorded and subtracted from 100.

Results and Discussion

Proximate composition

Table 1. Proximate composition of pearl and finger millet varieties grown in Zimbabwe

Parameters (%)	Pearl millet varieties			Finger Millet varieties	
	Okashana 1	PMV 2	PMV 3	FMV 1	FMV 2
Moisture	13.10±0.14^{ab}	12.15±0.21^{a}	13.45±0.07^{b}	13.15±0.49^{ab}	13.55±0.07^{b}
Carbohydrates	65.57±0.10^{b}	69.23±0.13^{c}	64.53±0.08^{a}	72.57±0.42^{e}	69.91±0.01^{d}
Crude Protein	9.81±0.01^{d}	7.29±0.01^{b}	10.92±0.02^{e}	5.98±0.03^{a}	9.14±0.02^{c}
Crude Fat	5.39±0.02^{c}	6.10±0.04^{e}	5.97±0.05^{d}	1.95±0.02^{b}	1.49±0.02^{a}
Crude Ash	2.93±0.04^{d}	2.13±0.04^{b}	1.83±0.04^{a}	2.95±0.06^{d}	2.36±0.04^{c}
Crude Fibre	3.20±0.14^{a}	3.10±0.14^{a}	3.30±0.14^{a}	3.40±0.14^{a}	3.55±0.07^{a}

Data presented as mean ± standard deviation (n = 2). Means with the different letters (superscript) in the same row indicate values that are significantly different ($P \leq 0.05$).

Moisture content

Moisture content is a crucial parameter for the storage of grains including millet. Generally, the ideal is to have grains and flour with a lower moisture content as this helps them achieve a longer shelf life. Several authors have recorded the moisture content of pearl millet to be 6.85% (Efe-Ejiofor & Oparaodu, 2019), 11.31 % (Munchi & Dashora, 2024), and 12.05 % (Verma *et al.*, 2025) and 12.2 % (Pawar *et al.* 2020). Shankaramurthy and Somannavar (2019), recorded a moisture level of 12.86 % in finger millet while other authors found it to be 7.30 % (Eke-Ejiofor & Oparaodu, 2019); 9.15 % (Verma *et al.*, 2025) and 12.69 % (Munshi & Dashora, 2024). The differences observed could be due to grain moisture content before milling, milling processes and storage conditions. Grains from humid areas tend to have a high moisture content, while wet milling produces flour with a higher moisture content when compared to dry milling due to the soaking step (Puramshetty *et al.*, 2025) and flours stored in airtight containers tend to be drier than those stored in packages that generate moisture (Jain *et al.* 2024).

Carbohydrates

The carbohydrate content range observed in this study for pearl millet and finger millet varieties is within the ranges reported in literature. PMV 3 had the least carbohydrate content amongst both pearl and finger millet varieties. Shankaramurthy and Somannavar (2019), recorded a carbohydrate content of 66 % in pearl millet which is comparable to Okashana 1. In finger millet, Shankaramurthy *et al.* (2019) found the carbohydrate content to be 71% and it is comparable to FMV1 and FMV2 results found in this study. The carbohydrate content observed in this study reflects the starch packing density within the millet endosperm which occurs at multiple hierarchical levels such as molecular, helical, crystalline, and granular with amylose content critically influencing packing density (Shi *et al.,* 2023). The higher carbohydrate content in FMV 1 suggests densely packed starch granules with A-type crystalline structure typical of cereals (Thieme, 2024), contributing to its high-water absorption capacity as water molecules penetrate amorphous regions within the packed structure. Conversely, pearl millet varieties exhibited lower carbohydrate (64.53–69.23%) but higher fat content, indicating that lipid bodies are interspersed among starch granules, potentially affecting overall granule packing and contributing to their distinct functional properties. The variation in carbohydrate content among varieties likely reflects differences in amylose: amylopectin ratios, with higher amylose content generally associated with more rigid, compact granule structure (Shi *et al.,* 2023). Furthermore, the differences normally observed in different studies involving grains could be due to the genetic and environmental aspects that influence grain composition (Itiat and Grace, 2023). Current breeding initiatives intensively select specific carbohydrates such as high amylose or high fibre types and waxy types, these consequently affect the overall carbohydrate content (Saini *et al.*, 2020). Environmental aspects such as saline soils lead to reduced kernel size and starch content (Mukami *et al.*, 2020).

Crude protein

Overall, crude protein in both pearl and finger millet varieties significantly varied from each other. It corroborates with the findings of multiple researchers such as 10.50 % (Kumari *et al.*, 2022) and 10.57 % (Owheruo, Ifesan & Kolawole, 2019). However, Jandu and Kawatra (2019), reported a different protein range (11.81 to 12.48 %) among three pearl millet cultivars (HC-30, HHB-67 and WHC-901). FMV 2 recorded content comparable to the 9.53 % found in Milky cream finger millet variety (Ramashia *et al.*, 2019). In this current study, brown coloured finger millet varieties were used, and they had a protein content almost similar to the one reported by Ramashia *et al.*, (2019). The protein discrepancies may be linked to genetic, morphological, and agronomic variations (Anitha *et al.*, 2024). Additionally, the different analytical methods adopted by authors for the estimation of parameters could also be a reason for the variance (Anitha *et al.*, 2024).

Crude Fat

In this present research, all the pearl millet varieties had more fat than the finger millet varieties. This supports findings by Rani *et al.* (2018), that pearl millet generally has more fat than any other millet. The fat content in pearl millet was comparable to 6.87 % reported by Munshi and Dashora (2024). Due to its higher fat content than all the other cereal grains, pearl millet products have a low shelf life because of the oxidation of unsaturated fatty acids (Padmaja *et al.*, 2024). The fat content of finger millet in this study was 1.95 % for FMV 1 and 1.49 % for FMV 2. Jayawardana *et al.* (2019), reported a fat content range of 1.40 to 1.41 % in finger millet. Also, in the same grain Hiremath and Geetha (2019) found a fat content of 1.30 to 1.90 %.

Crude ash

The ash content reported in this study for pearl millet was higher than 1.57 % and 1.61 % reported by Eke-Ejiofor and Oparadou (2019) and Munshi and Dashora (2024), respectively. A similar trend was noted in finger millet. Verma *et al.* (2025), reported a lower ash content of 1.96 %. Ash content is generally considered an indicator of a food's mineral content (Eke-Ejiofor and Oparaodu, 2019), hence, pearl and finger millet flour contain significant amounts of minerals as per the findings of this study. A study by Joshi *et al.* (2025) postulated that environmental pressures like high temperatures, high saline soils, high salt levels, and low water accessibility can influence the mineral content variations in food. In addition, Anitha *et al.* (2024) alluded that the variations in pearl millet mineral content are mainly attributed to genotypic diversity.

Crude fibre

The findings of the study are comparable to the crude fibre of 3.87 % found in a South African variety (Hassan *et al.*, 2021). Finger millet generally has a crude fibre content that varies between 2.0 and 3.6 % (Gebre, 2019). The results observed in finger millet under study were in the general range stipulated by Gebre (2019). The variations are linked to genotypic attributes, prevailing climatic factors and soil nutrient quality (Dias-Martins, 2018).

Tannins

Table 2. Tannin content of pearl and finger millet varieties cultivated in Zimbabwe

Tannins

Parameter	**Pearl millet varieties**			**Finger Millet varieties**	
	Catechin equivalent (%)				
	Okashana 1	PMV 2	PMV 3	FMV 1	FMV 2
Tannin Content	0.107±0.000^c	0.071±0.000^b	0.020±0.001^a	0.200±0.000^d	0.406±0.000^e

Data presented as mean ± standard deviation (n = 2). Means with the different letters (superscript) in the same row indicate values that are significantly different (P ≤ 0.05).

Tannins are one of the main antinutrients found in finger millet (Gebre, 2019). There were clear differences in tannin content among the millet varieties in this study. FMV 1 and FMV 2 showed higher tannin contents which fall in the general range of 0.04 - 3.74 % as suggested by Gebre, 2019. In comparison, pearl millet had lower values with PMV having the lowest tannin content. The recorded values are also comparable to those reported in a study by Samtiya *et al.* (2021), who reported tannin contents of 3.07-4.35 mg/g (0.307-0.435 %) in pearl millet flours. Other studies have also reported generally low tannin content in millets, which can range widely depending on genotype and grain colour, where coloured varieties have more tannins than the white ones (Aanchal *et al.*, 2024). Additionally, finger millet often exhibits higher condensed tannins compared to pearl millet. This is because of its testa, which has multiple layers such that it binds more phenolics (Ramashia *et al.*, 2025). This aligns with the higher tannin levels observed in the finger millet varieties in this study. In general, tannins form complexes with proteins, inhibiting digestive enzymes and lowering protein digestibility (Sheethal *et al.*, 2022). This alters the nutritional quality of the flours if they are to be are used in complementary or weaning foods.

Despite the absence of processing, the low tannin levels observed in raw pearl millet varieties indicate that these are inherently low-tannin cultivars, which is a good trait for nutritional quality. Tannin content in millets is primarily genetically controlled, with wide variation existing among cultivars, i.e. low tannin varieties exist naturally (Khatri et al., 2023).

However, various processing methods can further reduce tannin concentrations. Dehulling, soaking and roasting as pre-processing techniques reduce tannin content and have been proven to increase the in vitro protein digestion of pearl millet (Samtiya *et al.*, 2021). Also, germination has been reported to reduce tannin levels in both finger and pearl millets as it facilitates leaching and enhanced enzymatic breakdown of polyphenols (Karki *et al.*, 2024). However, tannins that are found in the testa and are not involved directly in germination can become relatively concentrated in pearl millet grains, especially at higher germination temperatures (Sneha *et al.*, 2023). These factors should always be considered when there are product applications that require high protein quality or low antinutrient content.

Functional Properties

Table 3. Functional properties of pearl and finger millet varieties grown in Zimbabwe

Parameters	**Pearl millet varieties**			**Finger millet varieties**	
	Okashana 1	PMV 2	PMV 3	FMV 1	FMV 2
Water absorption capacity (ml/g)	1.32±0.05a	1.21±0.10a	1.26±0.07a	1.34±0.07a	1.29±0.08a
Oil absorption capacity (m/gl)	1.16±0.02a	1.35±0.01a	1.17±0.12a	1.17±0.19a	1.44±0.08a
Dispersibility (%)	73.33±0.58a	74.66±1.52a	75.33±1.52a	79.33±0.58b	75.00±2.00a

Data presented as mean ± standard deviation (n = 2). Means with the different letters (superscript) in the same row indicate values that are significantly different ($P \leq 0.05$).

Water absorption capacity

The recorded water absorption capacity (WAC) of the pearl millet varieties under study were similar to 1.13 ml/g reported by Ramashia *et al.* (2019). Furthermore, the WAC of pearl millet flour was established to be between 1.54 and 1.86 ml/g by Pawase *et al.* (2021). The finger millet varieties used in this study had water absorption capacities which collaborated findings reported by Ramashia *et al.* (2019), who studied the WAC of finger millet flours and it varied from 0.93 to 1.23 ml/g. Khatonia and Das (2020), reported a WAC of 1.21 ml/g in finger millet flour.

High values of WAC are often associated with elevated levels of dietary fiber and protein. These enhance water binding through hydrogen bonding and capillary action within the flour (Mukhtar *et al.*, 2025). The relatively high WAC observed in both pearl and finger millet flours in this study can therefore be attributed to their high fiber content and complex proteins. The relatively high fiber content across all varieties provides abundant hydroxyl groups that form hydrogen bonds with water molecules, thereby contributing to water retention in the flour (Cheng *et al.,* 2026). The protein content, particularly in varieties such as PMV 3, contributes to WAC through the hydrophilic amino acid side chains that readily associate with water. The relatively low WAC observed in PMV 2 correlates with its lower protein content as compared to other pearl millet varieties (Flori and Alavi, 2023).

The relatively narrow range of WAC values recorded suggests that overall water-binding capacity of these flours is comparable. This can be as a result of the influence of starch (which constitutes the major fraction of the flours) on water absorption behavior. Starch granules absorb water and swell upon hydration. The degree of swelling is influenced by the amylose-to-amylopectin ratio and the crystalline structure of the granule (Saini *et al.,* 2020). Amylopectin, which is branched, creates open ends that easily bind to water whilst linear amylose packs densely and restricts the penetration of water. The higher WAC in FMV1 suggests amylopectin-dominated starch, while the lower WAC in PMV2 and PMV3 may suggest higher amylose that restricts absorption (Saini *et al.,* 2020).

Also, the fine particle size distribution resulting from milling (180 µm mesh) would have increased the surface area available for hydration, thereby potentially enhancing WAC in all the samples.

Flours such as these, with high water absorption capacity, can be used in food systems where moisture retention, dough consistency and viscosity development are important. Findings of this study therefore indicate that pearl and finger millet flour can successfully be used in the formulation, development and processing of baked products, porridges and composite flours (Culetu *et al.*, 2021).

Oil Absorption Capacity (OAC)

The oil absorption capacity of Okashana 1 was the least but was not significantly different from the other two pearl millet varieties. These findings are in agreement with those reported by Pawase *et al.* (2021), who found the OAC of five pearl millet varieties ranging from 1.23 to 1.57 ml/g. Such similarities suggest that oil-binding behaviour in pearl millet flours is relatively stable across varieties when processed under comparable conditions. The observed OAC of finger millet flours used in this study also align with the findings of Khatoniar and Das (2020).

OAC differences among millet flours can be influenced by grain composition. It is highly influenced by the presence of hydrophobic components in the flour matrices. The non-polar amino acid side chains (e.g., leucine, isoleucine, valine, phenylalanine) of proteins which attract oil molecules enhance the absorption of oil (Arepally *et al.,* 2023). Also, the hydrophobic components of starch and fiber can also entrap oil through physical encapsulation and surface adsorption. Additionally, the amount of fat naturally found in the flour (endogenous fat) may influence its ability to absorb additional oil, as the inherent fats make the flour matrix more hydrophobic (Hasmadi *et al.,* 2020)

FMV 2 showed the highest OAC despite having the lowest fat content among all varieties suggesting that in this case, proteins and the presence of hydrophobic amino acid residues are more dominant in oil binding rather than the endogenous fat. Okashana 1 showed the lowest OAC despite having moderate protein and fat content, indicating that for this variety, protein structure and hydrophobic sites may be more important than absolute protein quantity. The relatively higher OAC observed in PMV 2 correlates with its high fat content. This suggests that the endogenous lipids contribute to its hydrophobic nature. The PMV2 variety also had moderate protein content, which may provide additional oil-binding sites.

The practical importance of OAC is that it influences flavor retention, mouthfeel and palatability. Oil is a carrier of flavor compounds hence flours that have a good oil-binding ability retain aroma compounds during processing and cooking, enhancing the sensory quality of finished products (Hasmadi *et al.*, 2020). The moderate to high OAC values observed across all varieties suggest that they would do well in fried products, meat extenders, bakery items, and formulations where fat incorporation is desired (Ramashia *et al.,* 2019).

Dispersibility

Pearl millet varieties had a dispersibility similar to the findings of a study by Eke-Ejiofor and Oparaodu (2019), who found a dispersibility level of 73 % in pearl millet flour. In finger millet varieties, the dispersibility was higher in FMV 1 compared to FMV 2. Similarly, Bajo *et al.* (2021), found the dispersibility of finger millet flour to be 77. 333%.

Dispersibility is influenced by multiple compositional and physical factors. Factors such as particle size distribution, surface characteristics and flour matrix structure affect how flour particles are dispersed in aqueous systems. Finer particles with uniform size distribution tend to disperse more readily, while irregular or coarse particles are more likely to clump and form lumps (Lin *et al.,* 2019). The surface characteristics of flour particles depends on their surface properties, such as how well they attract water (hydrophilicity) and their electrical charge. These factors affect how they mix with water and their aggregation. In addition, the chemical composition of the flour, particularly the type and structure of its proteins and starch, also affects how the particles behave when water is added (Hasmadi *et al.*, 2020). High protein content can reduce dispersibility as the proteins may promote aggregation through hydrophobic interactions or disulfide bridging (Ramashia *et al.,* 2019). However, starch granules with intact structures tend to settle more rapidly than those with damaged surfaces. The hydrophilic nature of fibre may enhance dispersibility by promoting penetration of water and encouraging separation of particles.

In this study, FMV 1 demonstrated the highest dispersibility while having the lowest protein content. This suggests that the lower protein content may reduce aggregation, allowing particles to remain suspended. The pearl millet varieties (Okashana 1, PMV 2 and PMV 3) with higher protein content showed slightly lower dispersibility. This is consistent with the hypothesis that proteins can promote particle aggregation.

Overall, both pearl and finger millet varieties under study had high dispersibility values and this indicates that the flours will not clump or form lumps during rehydration. These characteristics are advantageous in foods where rapid and uniform dispersion is desired resulting in a smooth and consistent quality. The flours can be applied in the formulation of instant porridges, beverages, soup thickeners and dough systems. A smooth, lump-free consistency is an important quality attribute in complementary foods and instant mixes, where consumer acceptability depends on texture (Ramashia *et al.*, 2019)

Limitations

Tannins were determined using the Vanillin method. This is one of the most common methods used in tannin determination. However, HPLC-based methods that are more specific and sensitive could have been used for the analysis of tannins.

Conclusions

The study successfully established the baseline composition and quality traits of five Zimbabwean millet varieties. The study quantified the nutritional make-up of the grains. Carbohydrates were the highest component, ranging from 64.53% (PMV 3) to 72.57% (FMV 1). Crude protein varied significantly, with PMV 3 having the highest among pearl millets (10.92%) and FMV 1 the lowest overall (5.98%). Crude fat was distinctly higher in pearl millets (ranging from 5.39% to 6.10%) compared to finger millets (1.49% to 1.95%). Crude fibre was relatively consistent, ranging from 3.10% (PMV 2) to 3.55% (FMV 2). The study revealed a clear distinction of the tannin content between the grain types. Finger millet varieties contained significantly higher tannins, with FMV 2 recording the highest at 0.406% catechin equivalent. Pearl millet varieties had lower tannin levels, with PMV 3 having the lowest at just 0.020%. The study determined how the flours would behave during processing. Water Absorption Capacity (WAC) ranged from 1.21 ml/g (PMV 2) to 1.34 ml/g (FMV 1), indicating good moisture retention. While Oil Absorption Capacity (OAC) ranged from 1.16 ml/g (Okashana 1) to 1.44 ml/g (FMV 2), indicating good flavour retention and all varieties showed high dispersibility (>73%), with FMV 1 being the highest at 79.33%, suggesting they will not form lumps when mixed with water. In conclusion, while all varieties demonstrated potential for food product development, PMV 3 emerged as the most nutritionally valuable due to its high protein and low tannin content, making it ideal for complementary foods. Conversely, FMV 2 was distinguished by its high tannin and oil absorption capacity, rendering it suitable for traditional brewing and functional foods where antioxidant properties are desired. The selection of the best variety is therefore contingent upon the specific product application and target consumer needs.

The significance of this study is that it fills a critical research gap by providing the first comprehensive, published dataset on the proximate, functional, and anti-nutritional (tannin) properties of specific pearl (Okashana 1, PMV 2, PMV 3) and finger (FMV 1, FMV 2) millet varieties cultivated in Zimbabwe. Prior to this, despite government initiatives like Pfumvudza promoting small grains, the food industry and nutritionists lacked the empirical data needed to utilize these specific varieties. This study scientifically validates the nutritional potential of these indigenous crops, moving them from being characterized merely as "drought-tolerant" to being recognized as quantifiable "smart-nutri cereals" with specific industrial applications.
Beyond general knowledge about millets, this study provides specific new insights into Zimbabwean varieties. Varietal specificity highlighted that not all millets are the same. For example, within the pearl millets, PMV 3 (10.92% protein) is nutritionally superior in protein content to PMV 2 (7.29% protein). This allows for informed selection based on nutritional goals. Furthermore, the tannin-colour/type link provided specific data confirming that the finger millet varieties (FMV 1 and FMV 2) have significantly higher tannin levels than the pearl millet varieties. This quantifies the trade-off between their known antioxidant potential and the need for processing to improve protein digestibility. The study provides local data confirming that Zimbabwean pearl millet varieties have a fat content significantly higher than local finger millet varieties and even other cereals, which directly impacts their potential shelf-life stability in processed products.

Based on the specific functional and nutritional data, PMV 3 can be used in the production of high protein complementary foods such as infant porridges or weaning blends because it has the highest protein content (10.92%) and the lowest tannin content (0.020%) among the samples, meaning protein digestibility will be higher with less need for extensive pre-processing. FMV 2 has potential to be used in fermented alcoholic beverages such as the traditional opaque beer or functional foods targeting antioxidant benefits because of its high tannin content (0.406%) which is desirable for the characteristic astringency and clarity in traditional brewing. If used for food, the data signals that roasting or malting must be applied as a pre-processing step to reduce tannins. Furthermore, PMV 2 & FMV 2 can be employed in the production of flavour-intensive or fried products like extruded snacks, flatbreads with added fat. These varieties have the highest Oil Absorption Capacity (1.35 and 1.44 ml/g respectively). They can bind and retain fats and oil-soluble flavours effectively, enhancing the palatability and mouthfeel of fried or oil-rich snack foods.

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