Modelling Moisture-Dependent Effect on the Dimensional and Flowability Properties of Yellow and Brown Tigernut

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ABSTRACT

This study examines the moisture-dependent dimensional and flowability characteristics of yellow and brown tigernut (*Cyperus esculentus*) over a moisture content range of 15.45% to 36.20% (dry basis). The results indicate significant differences ($p<0.05$) in linear increases for the length, 8.49 to 10.38 mm, width, 8.48 to 9.73 mm and thickness, 8.11 to 9.19 mm for the yellow variety while the brown variety, ranges from 8.16 to 9.88 mm, 7.86 to 8.93 mm and 7.97 to 9.11 mm for length, width and thickness respectively. The bulk density and true density decreased with an increase in moisture content while porosity increased with the moisture content. There was an increase in the angle of repose from 29.10 to 41.30° and 21.15 to 37.85° for the yellow and brown varieties respectively. Also, the static coefficients of friction on glass, plywood, and stainless steel surfaces showed an increase with increased moisture content for both varieties. All examined properties displayed robust linear correlations with moisture content ($R^2 \geq 0.913$-0.998) for both varieties. These results provide essential design parameters for processing equipment, suggesting that the brown variety requires smaller hopper openings but less conveyor power than the yellow variety. The Principal Component Analysis (PCA) biplot suggests a variety-specific characteristic. These varietal differences highlight the necessity for color-specific processing approaches in the tigernut value chain.

Keywords: model, yellow and brown tigernut, moisture-dependent, dimension and flowability

INTRODUCTION

Tigernut (*Cyperus esculentus*), also known as yellow nutsedge, earth almond, or chufa, is a long-lived plant appreciated for its small, tuber-like roots that are nutrient-dense and versatile for a variety of applications in food processing. Originally from the Mediterranean and Africa, tigernut have gained international attention due to its high levels of oils, starch, minerals, and dietary fiber making them a sought-after ingredient for products free of gluten, beverages and foods with health benefits [3]. Despite its potential, tigernut is an underused crop that shows significant economic and nutritional potential, which has led to increased interest in food processing research due to their health advantages and versatility. The dimensional and engineering properties of tigernut, including their (length, width, thickness), related parameters (geometric and arithmetic mean diameters, surface area, sphericity, aspect ratio), angle of repose, and static coefficient of friction, are critical for assessing their effectiveness in handling, storage, and processing [11]. These properties are known to vary with moisture content, which is a crucial factor that affects swelling of kernel, flowability, and friction characteristics, which in turn impacts equipment design and post-harvest management strategies. [8]. Understanding these variations is vital for improving processing techniques, particularly as moisture levels fluctuate during storage or processing.

Recent studies have indicated that moisture content significantly impacts the physical properties of agricultural products, tigernut inclusive. For instance, increased moisture content has been associated with enhanced dimensional characteristics due to water absorption and swelling, similar to what is observed in grains and nuts [5]. Additionally, engineering characteristics such as the angle of repose and static coefficient of friction are influenced by moisture levels, with increased moisture typically resulting in reduced flowability and heightened frictional resistance because of increased cohesion and surface adhesion [4]. Research on different varieties of black tigernut revealed variations in size and shape, which may affect their moisture response [1]. Nonetheless, there is a lack of extensive data comparing dimensional and flowability properties across various moisture levels at dry basis for both yellow and brown varieties, highlighting the need for thorough research.

Modelling the moisture-dependent behavior of tigernut involves developing mathematical equations that connect moisture levels to dimensional and flowability characteristics, typically using empirical, statistical, or mechanistic approaches. These models assist in the design of equipment by specifying operational parameters such as dryer airflow rates, mill screen sizes, or mixer speeds, which are adapted to the unique properties of the material. Therefore, the aim of this study is to investigate how moisture content (expressed on a dry basis) affects the dimensional and flowability properties of yellow and brown tigernut varieties and to create a mathematical model that predicts the relationship between moisture content and these properties, which can be utilized in the design of processing equipment.

MATERIALS AND METHODS

Sample Preparation

The fresh tigernut tubers utilized for this research were obtained from the “Ama Hausa” market located in Owerri, Imo State, Nigeria. The tigernut was sorted and cleaned. The moisture content of the tigernut was assessed using the method outlined by [12] with slight modifications. The tigernut was dried in a hot air oven (Gallenkamp model, UK) at 105ºC for 48 hr to ensure consistent moisture content. After 48 hr, the moisture content of the tigernut was found to be 15.45% on a dry basis (db). Subsequently, the tigernut was divided into five separate batches of 100 grams each. Four of these batches were then conditioned with specific amounts of water to achieve different moisture contents of 19.10%, 24.28%, 30.51%, and 36.20% on a dry basis (db) using equation 1 as referenced by [12] with slight modifications. The four conditioned tigernut were stored in an airtight polythene bag and kept at 4 ºC in a refrigerator to ensure equal moisture content for all tigernut before analysis.

$$Q = Wi\left(\frac{Mf - Mi}{100 - Mf}\right) \quad (1)$$

Where,

Q = Mass of added water (g),

W_i = Initial mass of the tigernut (g),

Mi = Initial moisture content of the tigernut (%, db), and

M_f = Final moisture content of the tigernut (%, db).

Methods

Determination Of Dimensional Properties

The length (L, mm), width (W, mm), and thickness (T, mm) of the 50 tigernut were randomly measured and recorded using a digital Vernier caliper, which has an accuracy of 0.001 mm. The geometric mean diameter (Dg, mm), sphericity (φ), surface area (Sa, mm^2), and aspect ratio (Ra) were computed using Equations 2, 3, 4, and 5 as referenced in [7].

$$Dg = \sqrt[3]{L*W*T} \quad (2)$$

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$$\Phi = \frac{Dg}{L} \qquad (3)$$

$$Sa = \pi (Dg)^2 \qquad (4)$$

$$Ra = \frac{W}{L} \qquad (5)$$

Where,

L = length, W = width, T = Thickness, Dg = geometric mean diameter,

Determination Of Flowability Properties

The bulk density (*Pb*) (g/cm^3), true density (*Pt*) (g/cm^3), and porosity (%), were determined following the methods as described in [7] with minor modifications and performed in triplicate. The tigernut was placed in a 250 cm^3 measuring cylinder, and after tapping the cylinder ten times, the mass was recorded. The bulk density was calculated by dividing the mass of the tigernut by the volume it occupied. The true density was measured using a method where toluene is displaced. A 100 mL cylinder contained a fixed volume of toluene (50 mL), into which approximately 5 g of tigernut was submerged. The increase in the toluene volume was measured, and the true density was found by dividing the mass by the volume increase. Equation 6 was used to calculate porosity.

$$\varepsilon = (1 - \frac{Pb}{Pt}) * 100 \qquad (6)$$

The method of [7] was used to determine the angle of repose and static coefficient of friction as shown in Equation 7 and 8.

$$\theta = \tan^{-1} \frac{2H}{D} \qquad (7)$$

Where,

H= Pile height (mm),

D= Pile diameter (mm)

$$\mu = \tan \beta \qquad (8)$$

Where,

μ = Static coefficient of friction for the structural material

β = angle of inclination

Note: $\beta = \tan^{-1} i.e \frac{\text{Vertical height of inclined plane}}{\text{Base length of the platform}}$

Statistical Analysis And Model Fitting

Paired t-test was used to compare the means of both tigernut at ($p<0.05$) significant level. The mathematical linear model was fitted into the data obtained from the analysis. All data including Principal Component Analysis (PCA) were analyzed using Origin Pro software 2018.

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RESULTS AND DISCUSSION

Moisture-Dependent Effect on The Dimensional Properties of Tigernut

The moisture-dependent dimensional properties and modeling equations of yellow and brown tigernut are presented in Table 1. Additionally, Table 1 includes the metrics, coefficient of determination (R^2), root mean square error (RMSE), and chi-square (X^2) of the model equations. As the moisture content increased, the mean dimensions (length, width, thickness) for the yellow variety ranged from 8.49 to 10.38 mm, 8.48 to 9.73 mm, and 8.11 to 9.19 mm, while for the brown variety, it ranged from 8.16 to 9.88 mm, 7.86 to 8.93 mm, and 7.97 to 9.11 mm respectively. Increased moisture content resulted in the swelling of tigernut cell walls and increased turgor pressure, which caused cellular expansion and stretching in the primary dimensions: for the yellow variety, the swelling was 0.0558 mm/%MC (length), 0.0355 mm/%MC (width), and 0.0356 mm/%MC (thickness); for the brown variety, it was 0.0524 mm/%MC (length), 0.0339 mm/%MC (width), and 0.0347 mm/%MC (thickness). These increases in dimensions were significantly different ($p<0.05$) between the two varieties. Previous research ([2], [14]) indicated that lower moisture content resulted in smaller dimensions.

As moisture content increased, the geometric mean diameter of the yellow variety increased from 8.36 to 9.75 mm (0.0421 mm/%MC) and their surface area expanded from 219.47 to 298.93 mm² (2.3943 mm²/%MC). For the brown variety, the diameter increased from 8.00 to 9.30 mm (0.0408 mm/%MC) and surface area, from 200.85 to 271.58 mm² (2.1764 mm²/%MC), indicating a similar swelling pattern. Although the differences remained significant ($p<0.05$), a robust linear relationship ($R^2 = 0.99$) was identified, with the yellow variety consistently displaying larger dimensions, and greater surface area compared to the brown variety, which aligns with findings from [11].

The sphericity (Φ) of the yellow variety decreased from 0.98 to 0.94 (-0.0012/%*MC*), a value slightly less than 0.99 to 0.94 (-0.0014/%*MC*) for the brown variety. As the moisture content increased, both varieties became less spherical but almost spherical at low moisture content with no significant difference ($p<0.05$). The brown variety displayed a slightly more pronounced trend in sphericity, potentially due to greater elongation during water absorption, whereas the yellow variety exhibited more uniform elongation. In contrast, [11] reported an increase in sphericity from 0.931 to 1.011 as moisture content increased from 7% to 16% (wb). The aspect ratio (Ra) of the yellow variety decreased from 1.00 to 0.94 (-0.0020/%*MC*), slightly faster than 0.96 to 0.90 (-0.0017/%*MC*) for the brown variety as the moisture content increased. This suggests a change in shapes due to variability and a faster dimensional elongation of the yellow variety over the brown variety which is not significantly different ($p<0.05$). Also, the aspect ratio decreased with an increase in moisture content with the yellow variety having higher values than the brown variety which suggests a faster dimensional elongation of the yellow variety over the brown variety.

Moisture-Dependent Effect On The Flowability Properties Of Tigernut

The data obtained for the flowability properties, model equations and their metrics, coefficient of determination (R^2), root mean square error (RMSE), and chi-square (X^2) of the model equations are shown in Table 2. The bulk density (Pb) refers to the mass of tigernut per unit of volume, including the spaces between particles. The mean values decreased from 0.69 g/cm³ to 0.51 g/cm³ (-0.0054 g/cm³/%*MC*) and 0.75 g/cm³ to 0.55 g/cm³ (-0.0061 g/cm³/%*MC*) as moisture content increased for the yellow and the brown varieties respectively. This reduction in bulk density with higher moisture is attributed to the expansion of tigernut, which increases their volume while the mass gain (from the added water) is not as significant. Furthermore, water may decrease the cohesion between particles, creating more void spaces and further reducing bulk density. [12] reported an increase from 0.59 g/cm³ to 0.63 g/cm³ and 0.60 g/cm³ to 0.64 g/cm³ as moisture content rose from 20% to 40% wet basis which is contrary to my findings. This could be due to differences in varieties or the moisture basis (wet basis vs. dry basis). However, an increase in bulk density with an increase in moisture content was reported by [13] for yellow, purple and black wheat grains.

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Table 1. Moisture-dependent effect on dimensions and model equations of yellow and brown tigernut

MC (%) db	Variety	Dimensional properties						
		L(mm)	W(mm)	T(mm)	Dg(mm)	Sa(mm^2)	Φ	Ra
15.45	Yellow	8.49_a	8.48_a	8.11_a	8.36_a	219.47_a	0.98_a	1.00_a
	Brown	8.16_b	7.86_b	7.97_b	8.00_b	200.85b	0.99_a	0.96_a
19.10	Yellow	9.01_a	8.88_a	8.23_a	8.70_a	237.78a	0.97_a	0.99_a
	Brown	8.51_b	8.01_b	8.23_a	8.25_b	213.69b	0.97_a	0.94_a
24.28	Yellow	9.42_a	9.14_a	8.59_a	9.04_a	256.93a	0.96_a	0.97_a
	Brown	8.92_b	8.26_b	8.49_b	8.55_b	229.78b	0.96_a	0.93_a
30.51	Yellow	9.87_a	9.34_a	9.01_a	9.40_a	277.59a	0.95_a	0.95_a
	Brown	9.41_b	8.67_b	8.83_b	8.96_b	252.46b	0.95_a	0.92_a
36.20	Yellow	10.38_a	9.73_a	9.19_a	9.75_a	298.93a	0.94_a	0.94_a
	Brown	9.88_b	8.93_b	9.11_b	9.30_b	271.58b	0.94_a	0.90_a
Model equation						R^2	RMSE	X^2
Yellow	$L = 0.0558\ \%MC + 7.6879$					0.99437	6.36E-02	4.05E-03
Brown	$L = 0.0524\ \%MC + 7.3374$					0.99809	0.03472	0.00121
Yellow	$W = 0.0355\ \%MC + 8.0024$					0.97861	0.07957	0.00633
Brown	$W = 0.0339\ \%MC + 7.2860$					0.98446	0.06448	0.00416
Yellow	$T = 0.0356\ \%MC + 7.5124$					0.97978	0.07745	0.006
Brown	$T = 0.0347\ \%MC + 7.4399$					0.99748	0.02644	6.99E-04
Yellow	$Dg = 0.0421\ \%\ MC + 7.7349$					0.99831	0.02623	6.88E-04
Brown	$Dg = 0.0408\ \%\ MC + 7.3572$					0.99615	0.03774	0.00142
Yellow	$Sa = 2.3943\ \%\ MC + 183.196$					0.99884	1.23768	1.53185
Brown	$Sa = 2.1764\ \%\ MC + 165.5525$					0.99420	2.51927	1.53185
Yellow	$\Phi = -0.0012\ \%\ MC + 0.9988$					0.94248	0.00459	2.10E-05
Brown	$\Phi = -0.0014\%\ MC + 1.0050$					0.93573	0.00542	2.94E-05
Yellow	$Ra = -0.0020\ \%\ MC + 1.0288$					0.98426	0.00374	1.40E-05
Brown	$Ra = -0.0017\ \%\ MC + 0.9831$					0.94853	0.00586	3.43E-05

Values are in mean (n=50). Mean values with different subscript on the same column are significantly different at ($p<0.05$) level. (Where, L=Length, W=Width, T=Thickness, Dg=Geometric mean diameter, Sa=Surface area, Φ=Sphericity, Ra=Aspect ratio, MC=Moisture content, db=dry basis)

True density (*Pt*) is defined as the mass per unit volume of the solid material, excluding voids, and the mean values from this study decreased from 1.22 g/cm³ to 1.03 g/cm³ (-0.0058 g/cm³/%*MC*) for yellow variety and 1.26 g/cm³ to 1.03 g/cm³ (-0.0070 g/cm³/%*MC*) for the brown variety. This decline suggests that water (with a density of around 1 g/cm³) replaces air (which has a negligible density) within the structure of the tuber, leading to an increase in its volume. The decrease is slightly greater than that of the bulk density, reflecting the significant effect of water incorporation on the density of the solid material. True density is important to calculate porosity and evaluate the compactness of a material. It also plays a critical role in the design of drying systems, as denser materials (for example, 1.22 g/cm³ at 15.45% *MC*) may necessitate longer drying durations. In the food processing industry, true density will influence how tigernut particles will behave during sedimentation in liquids when extracting its milk. [12] reported an increase of 0.005 g/cm³%*MC* with the coefficient of determination (R^2 = 0.823) for the yellow variety and a decrease of -0.006 g/cm³%*MC* with the coefficient of determination (R^2 = 0.661) for the brown variety.

The porosity (ε) represents the percentage of void space within the bulk material. The mean values of porosity for both yellow and brown varieties increased with increasing moisture content. This could be attributed to the decrease in the bulk density at a faster rate than the true density. The swelling caused by water at 0.2092%/%*MC* for the yellow variety and 0.1923%/%*MC* for the brown variety expanded the volume of the tigernut, which led to additional voids between particles and were significantly different ($p<0.05$). Porosity has implications for aeration and drying rates. Elevated porosity (50.49% at 36.20% *MC*) promotes airflow, accelerating drying but also heightening the risk of microbial growth if not adequately dried. This finding is similar to that of [13] for yellow, purple and black wheat grains that increased with moisture content but contrary to [12], which reported a decrease in porosity with an increase in moisture content from 20% to 40% of -0.15%/%*MC* with coefficient of determination (R^2 = 0.677) for the yellow variety and -0.618%/%*MC* with coefficient of determination (R^2 = 0.818) for the brown variety respectively.

The angle of repose (θ) is the maximum angle at which a pile of material maintains stability. The mean value of the yellow variety increased from 29.10 to 41.30° (0.3679°/%*MC*), and 21.15 to 37.85° (0.4956°/%*MC*) for the brown variety respectively. This increase in moisture content boosted inter-particle cohesion and surface stickiness which decreased the flowability of the tigernut. At higher moisture levels (36.20%), the tigernut has a greater tendency to clump together, necessitating a steeper angle for maintaining stability. The high coefficient of determinations (R^2 = 0.97992 and 0.99550 for both varieties) suggests a consistent influence of moisture on the flow behavior of tigernut. However, the brown tigernut exhibited superior flowability (lower θ) than the yellow variety, likely attributed to a smoother texture or reduced stickiness. This finding is consistent with [9], which reported an increase in the angle of repose with increased moisture content from 10 to 20% wet basis.

The static coefficient friction (μ) quantifies the resistance encountered between tigernut and various surfaces (glass, plywood, and stainless steel). The highest friction is observed on glass (1.43 at 36.20% *MC*), followed by stainless steel (1.31) and plywood (1.19) for the yellow variety and 1.12 at 48.20%*MC* for glass, 0.99 for stainless steel and 1.06 for plywood of the brown variety which is significantly different at ($p<0.05$). Yellow variety demonstrated increased static friction, potentially due to a rougher or stickier surface. These variations could be attributed to differences in surface roughness and wettability. Glass, having a smoother texture, can retain more water, which boosts adhesion, while the porous nature of plywood may absorb some moisture, thus lessening friction. These findings are similar to the values reported by [12] and [13] where there was an increase in the static coefficient of friction with an increase in moisture content.

Principal Component Analysis (Pca)

The PCA biplot (scores and loading plots) with PC1 accounting for 86.65% and PC2 11.87% resulting in a cumulative variance of 98.52 % for yellow and brown tigernut is shown in Figure 1. The goal of the PCA is to reduce the dimensionality of 14 variables while uncovering trends associated with moisture content and variety. The scores of PC1indicates a strong positive correlation with moisture content (e.g., Y15.45 at -2.734 to Y36.20 at 5.820 for yellow; B15.45 at -5.922 to B36.2 at 3.035 for brown), suggesting influenced by moisture changes in length, width, thickness, geometric mean diameter, surface area, bulk density, true density and porosity. This increase, thus reflects swelling with increased moisture content. Porosity increased as moisture content increases but bulk and true densities are higher at increased moisture content. The rising PC1 scores with increased

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moisture content (e.g., Y36.20 at 5.820) further confirmed this pattern. However, the scores of PC2, differ by variety (e.g., Y15.45 at 1.794 compared to B15.45 at -0.376), implying variety-specific characteristics or coefficient of static properties (glass, plywood, and stainless steel).

Table 2. Moisture-dependent effect on flowability and model equations of yellow and brown tigernut

Flowability properties								
MC(%) db	Variety					Static coefficient of friction(μ)		
		Pb(g/cm³)	*Pt* (g/cm³)	ε (%)	θ (°)	μgs	μpws	μsss
15.45	Yellow	0.69_a	1.22_a	43.44_a	29.10_a	1.13_a	0.98_a	1.04_a
	Brown	0.75_b	1.26_b	40.48_b	21.15_b	0.91_b	0.77_b	0.83_b
19.10	Yellow	0.66_a	1.18_a	44.07_a	32.75_a	1.17_a	1.04_a	1.11_a
	Brown	0.70_b	1.20_a	41.67_b	25.55_b	1.01_b	0.85_b	0.93_b
24.28	Yellow	0.61_a	1.14_a	46.49_a	36.50_a	1.21_a	1.09_a	1.16_a
	Brown	0.63_a	1.15_a	45.22_b	29.80_b	1.07_b	0.91_b	1.00_a
30.51	Yellow	0.57_a	1.08_a	47.22_a	39.00_a	1.29_a	1.13_a	1.27_a
	Brown	0.59_a	1.08_a	45.37_b	33.35_b	1.12_b	0.99_b	1.06_b
36.20	Yellow	0.51_a	1.03_a	50.49_a	41.30_a	1.43_a	1.19_a	1.31_a
	Brown	0.55_b	1.03_a	46.60_b	37.85_b	1.18_b	1.07_b	1.11_b
Model equation						R^2	RMSE	X^2
Yellow	$Pb = -0.0054 \% MC + 0.7782$					0.99484	0.00593	3.52E-05
Brown	$Pb = -0.0061 \% MC + 0.8360$					0.98517	0.01141	1.30E-04
Yellow	$Pt = -0.0058 \% MC + 1.3112$					0.99493	0.00626	3.92E-05
Brown	$Pt = -0.0070 \% MC + 1.3624$					0.99443	0.00792	6.27E-05
Yellow	$\varepsilon = 0.2092 \% MC + 39.7934$					0.95585	0.6813	0.46416
Brown	$\varepsilon = 0.1923 \% MC + 37.8476$					0.91294	0.89984	0.80972
Yellow	$\theta = 0.3679 \% MC + 34.2149$					0.97992	0.79807	0.63691
Brown	$\theta = 0.4956 \% MC + 24.0285$					0.9955	0.50516	0.25519
Static coefficient of friction (μ)								
Yellow	$\mu gs = 0.0087 \% MC + 1.9729$					0.93123	0.03593	0.00129
Brown	$\mu gs = 0.0078 \% MC + 1.8146$					0.96717	0.02171	4.71E-04
Yellow	$\mu pws = 0.0061 \% MC + 1.8942$					0.9906	0.00905	8.18E-05
Brown	$\mu pws = 0.0089 \% MC + 1.6394$					0.99453	0.01	1.00E-04

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Yellow	$\mu sss = 0.0084\ \%\ MC + 1.9145$	0.97904	0.01867	3.48E-04
Brown	$\mu sss = 0.0083\ \%\ MC + 1.7275$	0.96867	0.02251	5.07E-04

Values are in mean (n=3). Mean values with different subscript on the same column are significantly different at ($p<0.05$) level. (Where, Pb=bulk density, Pt=true density, ε=porosity, ϴ=angle of repose, µgs =static coefficient of friction on glass surface, µpws=static coefficient of friction on plywood surface, µsss=static coefficient of friction on stainless steel surface)

The yellow variety exhibited greater PC1 and PC2 scores (e.g., Y24.28 at 1.257, 1.132 compared to B24.28 at -1.286, -1.135), whereas the brown variety recorded lower and more negative scores on PC2 (e.g., B36.20 at 3.035, -1.876). This distinction suggests that the yellow variety (which probably contains larger starch granules) has a greater tendency to swell and demonstrate increased friction, while the brown variety (which is denser, with probably smaller granules) would behave differently. Consequently, aspect ratio has minimal or no effect on both moisture level and variety.

The implication of these patterns suggests the need for adjustable sorting and conveying systems to manage changes in size at high moisture content (Y36.20), while drying methods need to accommodate size reduction at low moisture content (B15.45). The predominance of PC1 indicates that bin designs should consider variations in bulk and true densities and porosity, with lower PC1 scores (such as B15.45) signifying increased porosity for planning storage volume. The 11.87% variance in PC2 emphasizes the significance of surface materials. The greater friction observed in the yellow variety under increased moisture content (e.g., Y32.28) suggests that smoother surfaces, like stainless steel, are preferable to minimize sticking during processing, The elevated PC1 scores for the yellow variety make them more suitable for applications that require softer textures (like milk production), while the lower scores and greater stability of the brown variety make them more appropriate for extended storage.

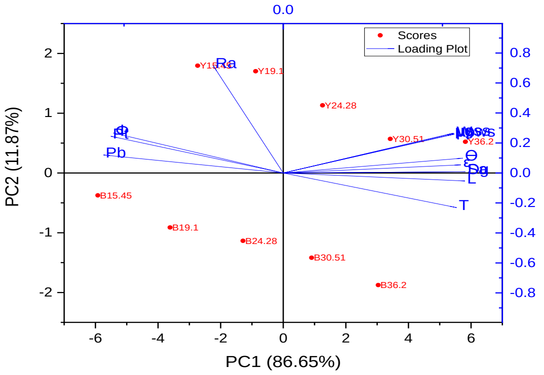

Figure 1: PCA plot of yellow and brown tigernut at different moisture content (db)

Where, L=Length, W=Width, T=Thickness, Dg=Geometric mean diameter, Sa=Surface area, Φ=Sphericity, Ra=Aspect ratio, db=dry basis Pb=bulk density, Pt=true density, ε=porosity, ϴ=angle of repose, µgs =coefficient of friction on glass surface, µpws=coefficient of friction on plywood surface, µsss=coefficient of friction on stainless steel surface

CONCLUSION

The study showed that moisture content has a considerable impact on the dimensional and flowability properties of yellow and brown tigernut, revealing a definitive pattern of increasing dimensions (L, W, T, Dg, Da, Sa) and frictional resistance (µ) while exhibiting a decline in sphericity (Φ), aspect ratio (Ra), and flowability (θ) as moisture content rose from 15.45% to 36.20% db. The brown tigernut exhibited enhanced processing traits owing to their more rounded shape and improved flowability, while yellow tigernut displayed larger average sizes but less favorable handling attributes. These results offer critical insights for industrial processing, suggesting that brown tigernut are more appropriate for automated systems, while emphasizing the necessity for moisture control and optimized handling equipment for the yellow variety, to further improve processing efficiency and product quality in the expanding tigernut sector. The PCA findings account for 98.52% of the variance, with PC1 (86.65%) emphasizing moisture-related variations in dimensions and porosity, while PC2 (11.87%) signify differences in shape and friction that are specific to each variety.

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