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Grade Classification for Water Chestnuts, their Dimensional Properties and Correlation Analysis

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The aim of the present study was to devise the grade classification for whole water chestnuts and kernels and to determine their dimensional properties. The data generated during the study will help in designing post-harvest handling equipments for water chestnuts in future. The mean values of length, width and thickness for whole water chestnuts ranged between ≤ 30 - > 45mm; ≤ 23- > 35mm and ≤ 9 - >18mm from grade I (very small) to grade V (very large) respectively, whereas, the corresponding values for whole water chestnut kernels ranged between ≤ 18 - > 36 mm; ≤ 13- > 22mm and ≤ 7 - > 16 mm from grade I to grade V respectively. For all the five devised grades, the mean values of derived dimensional properties were significantly ($p<0.05$) different in both whole water chestnuts as well as in kernels. Correlation analysis revealed significant ($p<0.05$) positive correlation among all the dimensional properties of whole water chestnuts. In case of whole water chestnut kernels, all the dimensional properties showed significant positive correlation with each other, except sphericity and aspect ratio, which showed non-significant positive and negative correlations with all the dimensional properties respectively.

Keywords: Whole water chestnuts, Kernels, Grade classification, Dimensional properties, Correlation

Introduction

In Jammu and Kashmir state, water chestnuts (*Trapanatans*) after harvesting are marketed as mixed lots without any grade classification which limits their industrial use and value addition. The large variability in the dimensions of water chestnuts in Kashmir puts forth the challenge in designing machinery for its post-harvest handling and processing. The present study was thus aimed to devise size-based grade classification for whole water chestnuts and kernels so as to bring mechanization in the value chain of this underutilized crop and to boost its market value.

Material and methods

Dimensional properties

Whole water chestnuts as well as kernels (100kg each) selected randomly were evaluated for principal dimensions (length, width and thickness) using electronic digital caliper having an accuracy of 0.001mm. The derived dimensional properties like equivalent diameter, geometric diameter, arithmetic diameter, sphericity, area of transverse surface, aspect ratio, volume and surface area for whole water chestnuts as well as kernels were calculated from principal dimensional values (L, W, T) using the following relationships

Equivalent diameter (D_e) = $\left[\frac{L(W+T)^2}{4}\right]^{1/3}$

Geometric diameter (D_g) = $(LWT)^{1/3}$

Arithmetic diameter (D_a) = $\frac{(L+W+T)}{3}$

Sphericity = $\frac{(LWT)^{1/3}}{L} \times 100$

Area of transverse surface = $\left[\frac{\pi}{4}\right] TW$

Aspect ratio = $\frac{W}{L}$

Volume = $0.25\left[\frac{\pi}{6}\ L(W+T)^2\right]$

Surface area = $\pi\ \times\ Dg^2$

Statistical analysis

All the experiments were carried out in triplicate and data was analyzed using single factor ANOVA. The Critical Difference (CD) was calculated at 5% level of significance. Correlation analysis was conducted using SPSS software.

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Results and Discussions

Dimensional properties of whole water chestnuts

Whole water chestnuts were classified into five grades based on their principal dimensions viz. length (L), width (W) and thickness (T) (Figure 1). The dimensional properties of whole water chestnuts are depicted in Table1. Length (L), width (W) and thickness (T) of Grade-I (very small), grade II (small), grade III (medium), grade IV (large) and grade V (very large) were significantly ($p<0.05$) different. The mean values of length, width and thickness ranged between ≤ 30 - > 45mm; ≤ 23- > 35mm and ≤ 9 ->18mm from grade I to grade V respectively (Table 1). These axial dimensions hold significance for computing the aperture size and spacing in sorting, shelling and grading machines. The dimensional properties of whole water chestnuts (principle as well as derived) showed an increasing trend from grade I (very small) to grade V (very large) (Table 1). The derived dimensional properties viz equivalent diameter, geometric diameter, arithmetic diameter, sphericity, area of transverse surface, aspect ratio, volume and surface area were found significantly different in all the five grades. These dimensional properties are size dependent and were derived from principle dimensions (i.e., L, W and T). The highest values as expected were obtained for grade V (very large) in all the derived dimensional properties. Equivalent diameter (D_e), geometric diameter (D_g) and arithmetic diameter (D_a) ranged between ≤ 19.72 to >31.61mm; ≤18.38 to >30.49 and ≤ 20.66 to >32.66mm from grade I to grade V respectively. Information about these properties i.e., D_e, D_g and D_a are useful in material separation and grading operations. Sphericity of classified grades (grade I to grade V) ranged between ≤61.26 to >67.75% respectively (Table 1). Sphericity values close to 100% indicate a perfect spherical shape. The lower values of sphericity obtained in case of whole water chestnuts were due to their triangular and irregular shapes. Aspect ratio is another factor which gives an idea about the oblong shape of the material. Aspect ratio of whole water chestnuts ranged between ≤ 0.766 to >0.777 from grade I to grade V respectively (Table 1) which indicates that water chestnuts have a tendency to slide rather than roll on flat surfaces. Sphericity and aspect ratio of the material are important parameters to be considered before designing hoppers and chutes in post-harvest handling and processing equipments. The mean values for area

Table 1 — Dimensional properties of whole water chestnut and kernels

Dimensional properties / Grades	Length (mm)	Width (mm)	Thickness (mm)	Equivalent Diameter (De) (mm)	Geometric diameter (Dg) (mm)	Arithmetic diameter (Da) (mm)	Sphericity (%)	Area of transverse surface (mm^2)	Aspect ratio	Volume (mm^3)	Surface area (mm^2)
Whole water chestnuts											
I (very small)	≤ 30	≤ 23	≤ 9	≤ 19.72	≤18.38	≤ 20.66	≤ 61.26	≤ 162.495	≤ 0.766	≤ 4016.64	≤ 1060.76
II (small)	>30 - ≤ 35	>23 - ≤ 27	>9 - ≤ 12	>19.72 – ≤23.69	>18.38 -≤22.46	>20.66 -≤24.66	>61.26-≤64.17	>162.495-≤254.34	>0.766 -≤0.771	>4016.64 -≤6960.47	>1060.76 - ≤1583.97
III (medium)	>35 -≤ 40	>27 - ≤ 31	>12 - ≤ 15	>23.69 – ≤27.65	>22.46 -≤26.49	>24.66 - ≤28.66	>64.17- ≤66.22	>254.34 -≤365.025	>0.771 -≤0.775	>6960.47-≤11066.68	>1583.97 -≤2203.40
IV (large)	>40 - ≤ 45	>31 - ≤ 35	>15 -≤ 18	>27.65 – ≤31.61	>26.49 - ≤30.49	>28.66 -≤32.66	>66.22-≤67.75	>365.025 -≤494.55	>0.775- ≤0.777	>11066.68-≤16527.45	>2203.40- ≤2919.06
V (very large)	> 45	> 35	> 18	>31.61	>30.49	>32.66	>67.75	>494.55	>0.777	>16527.45	>2919.06
CD ($p<0.05$)	2.01	1.60	1.18	1.59	2.22	1.76	1.37	0.041	0.011	0.048	0.005
Whole water chestnut kernels											
I (very small)	≤ 18	≤ 13	≤ 7	≤ 12.16	≤11.78	≤ 12.66	≥65.44	≤ 71.43	≥0.722	≤ 941.4	≤ 435.73
II (small)	>18 - ≤ 24	>13 - ≤ 16	>7 - ≤ 10	>12.16-≤15.94	>11.78 -≤15.65	>12.66 -≤16.66	≥65.20 – <65.44	>71.43 -≤125.6	≥0.666 - <0.722	>941.4 -≤2122.28	>435.73-≤769.05
III (medium)	>24 - ≤ 30	>16 - ≤ 19	>10 - ≤ 13	>15.94 -≤19.72	>15.65 -≤19.49	>16.66 - ≤20.66	≥64.96 – <65.20	>125.6 -≤193.89	≥0.633 - <0.666	>2122.28 - ≤4019.64	>769.05-≤1192.76
IV (large)	>30 - ≤ 36	>19 - ≤ 22	>13 - ≤ 16	>19.72 - ≤23.51	>19.49 -≤23.31	>20.66 - ≤24.66	≥64.75-<64.96	>193.89 - ≤276.32	≥0.611 - <0.633	>4016.64 - ≤6796.90	>1192.76- ≤1706.13
V (very large)	> 36	> 22	> 16	>23.51	>23.31	>24.66	<64.75	>276.32	<0.611	>6796.90	>1706.13
CD ($p<0.05$)	0.005	1.58	1.61	1.68	1.78	1.81	0.47	17.16	0.02	0.06	0.04

of transverse surface, volume and surface area ranged between ≤ 162.495 to >494.55mm^2; ≤ 4016.64 to >16527.45mm^3 and ≤ 1060.76 to >2919.06mm^2 from grade 1 to grade V respectively (Table 1). Volume of a material plays an important role in determining its packaging requirement while surface area and area of transverse surface are important parameters for heat and mass transfer calculations during drying and cooling operations. Similar trends for dimensional properties have been reported for shelled tamarind fruit and groundnut pods by Asoiro *et al*., 2017 and Muhammad *et al*., 2018 respectively.

Dimensional properties of whole water chestnut kernels

Whole water chestnut kernels were classified into five grades based on their size (Figure 2). Length, width and thickness of whole water chestnut kernels corresponding to Grade-I (very small), grade II (small), grade III (medium), grade IV (large) and grade V (very large) were significantly (P<0.05) different. The mean values of water chestnut kernels for length, width and thickness ranged between ≤ 18 - > 36 mm; ≤ 13- > 22mm and ≤ 7 - > 16 mm from grade I to grade V respectively (Table 1). All the derived dimensional properties viz equivalent diameter, geometric diameter, arithmetic diameter, sphericity, area of transverse surface, aspect ratio, volume and surface area were significantly (p<0.05) different for all the five grades. Equivalent diameter, geometric diameter, arithmetic diameter, area of transverse surface, volume and surface area of water chestnut kernels showed an increasing trend whereas, sphericity and aspect ratio showed a decreasing trend from grade I (very small) to grade V (very large) (Table 1). Equivalent diameter (De), geometric diameter (Dg) and arithmetic diameter (Da) of water chestnut kernels ranged between ≤ 12.16 to >23.51mm; ≤11.78 to >23.31 and ≤ 12.66 to >24.66mm from grade I to grade V respectively. Information about these properties i.e., D_e, D_g and D_a will help in designing of size based grader/separators for water chestnut kernels. Sphericity was found highest for grade I (≥65.44) and lowest for grade V (<64.75) (Table 1). This difference in sphericity of

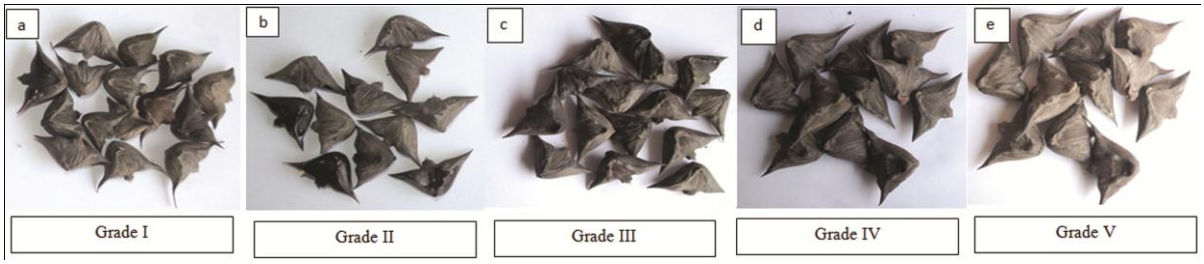

Fig.1 — Grade classification of whole water chestnut

Fig.2 — Grade classification of whole water chestnut kernels

water chestnut kernel grades could be attributed to difference in their axial dimensions. Aspect ratio was found in the range of 0.611 to 0.722 which indicates that any equipment/ machinery to be designed for grading and conveying of water chestnut kernels must work on sliding mechanism as the whole water chestnut kernels have tendency to slide rather than roll. The mean values of water chestnut kernels for area of transverse surface, volume and surface area ranged between ≤ 71.43 to >276.32mm^2; ≤ 941.4 to >6796.90mm^3 and ≤ 435.73 to >1706.13mm^2 from grade 1 to grade V respectively (Table 1). Almost similar results have been reported for cashew nut and its kernels by Pawar *et al*., 2017

Correlation among dimensional properties of whole water chestnuts

Table 2 demonstrates the correlation of various dimensional properties of whole water chestnuts. In case of whole water chestnuts, all the principal dimensional properties i.e., length (L), width (W) and thickness (T) as well as derived dimensional properties i.e., equivalent diameter (D_e), geometric diameter (D_g),

Table 2 — Correlation among different dimensional properties of whole water chestnuts

	Length	Width	Thickness	Equivalent Diameter	Geometric diameter	Arithmetic diameter	Sphericity	Area of transverse surface	Aspect ratio	Volume	Surface area
Length											
Width	0.996**										
Thickness	0.999**	0.997**									
Equivalent Diameter	0.995**	0.995**	0.996**								
Geometric diameter	0.988**	0.970**	0.983**	0.977**							
Arithmetic diameter	0.997**	0.998**	0.997**	0.999**	0.976**						
Sphericity	0.989**	0.985**	0.992**	0.997**	0.976**	0.992**					
Area of transverse surface	0.973**	0.980**	0.977**	0.990**	0.940*	0.986**	0.990**				
Aspect ratio	0.825	0.809	0.824	0.770	0.826	0.786	0.762	0.700			
Volume	0.952*	0.969**	0.957*	0.975**	0.907*	0.973**	0.968**	0.993**	0.651		
Surface area	0.960**	0.968**	0.964**	0.983**	0.926*	0.977**	0.982**	0.998**	0.654	0.995**	

*Correlation is significant at the 0.05 level
** Correlation is significant at the 0.01 level

Table 3 — Correlation among different dimensional properties of whole water chestnut kernels

	Length	Width	Thickness	Equivalent Diameter	Geometric diameter	Arithmetic diameter	Sphericity	Area of transverse surface	Aspect ratio	Volume	Surface area
Length											
Width	0.997**										
Thickness	0.993**	0.998**									
Equivalent Diameter	0.996**	0.990**	0.991**								
Geometric diameter	0.999**	0.993**	0.988**	0.995**							
Arithmetic diameter	0.997**	0.990**	0.984**	0.994**	0.999**						
Sphericity	0.209	0.266	0.260	0.151	0.172	0.142					
Area of transverse surface	0.984**	0.970**	0.959**	0.978**	0.991**	0.994**	0.090				
Aspect ratio	-0.751	-0.766	-0.804	-0.792	-0.738	-0.740	-0.032	-0.672			
Volume	0.973**	0.960**	0.943*	0.960**	0.982**	0.983**	0.125	0.996**	-0.608		
Surface area	0.977**	0.957*	0.952*	0.982**	0.983**	0.986**	0.021	0.990**	-0.710	0.976**	

*Correlation is significant at the 0.05 level
** Correlation is significant at the 0.01 level

arithmetic diameter (D_a), sphericity, area of transverse surface, volume and surface area exhibited significant positive correlation with each other except aspect ratio which showed non-significant correlation with all principal as well as derived dimensional properties (Table 2). Almost similar results were found by Ahad *et al*., 2017 in inshelled walnuts.

Correlation among dimensional properties of whole water chestnut kernels

Table 3 depicts the correlation coefficients between various dimensional properties of whole water chestnut kernels. In case of whole water chestnut kernels, all the principal dimensional properties (i.e., length (L), width (W) and thickness (T)) and almost all the derived dimensional properties (i.e., equivalent diameter (D_e), geometric diameter (D_g), arithmetic diameter (D_a), area of transverse surface, volume and surface area) exhibited significant positive correlation with each other, except sphericity and aspect ratio which exhibited non-significant positive and negative correlations with all the dimensional properties respectively (length (L), width (W), thickness (T), equivalent diameter (D_e), geometric diameter (D_g), arithmetic diameter (D_a), area of transverse surface, volume and surface area) (Table 3). Almost similar results have been reported by Masoodi *et al*., 2017 for whole almond and its kernels.

Conclusion

The outcome of the study was that, size-based grade classifications were devised for whole water chestnuts as well as kernels. Further, the main findings of the study were that the average values of derived dimensional properties viz., equivalent diameter, geometric diameter, arithmetic diameter, sphericity, area of transverse surface, aspect ratio, volume and surface area for whole water chestnuts increased with the increase in principal dimensional values from grade I to grade V. However, in case of whole water chestnut kernels sphericity and aspect ratio showed decreasing trend from grade I to grade V, while all other dimensional properties i.e., equivalent diameter, geometric diameter, arithmetic diameter, area of transverse surface, volume and surface area increased from grade I to grade V. The data generated during the present study will provide valuable insight for design and development of post-harvest handling and processing equipments/ machinery for water chestnuts in future.

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