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Effect of Pretreatment on Dimensional Properties of water Chestnut

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ABSTRACT: The aim of the study was to study effect of pretreatment on dimensional properties of water chestnut. To obtain good quality of water chestnut kernel and its flour, it is important to standardize pretreatment and its effect on dimensional parameters. For this, samples Water chestnut: Water ratio 1:1.5 was treated at 90ºC hot water for 30, 60 and 90 minutes and kept samples for 60,120 and 180 min as residence time inside the pressure vessels. The dimensional properties of whole water chestnut (WWC) and water chestnut kernel (WCK) were determined. On the basis of dimensional properties of WWC and WCK, it was found that if the graded sample treated for 60 min in hot water and then kept it for 120 min as residence time gave good quality of water chestnut kernels i.e. length, width, thickness, bulk density and hardness are 49.63 mm, 25.90 mm, 17.91 mm, 842.2 kg/m^3 and 24.89 N respectively. The outcome of this present study will give valuable insight for designing post harvest handling system for water chestnut.

Keywords: WWC, WCK, HWT, RT, Pressure vessel, Pretreatment, Dimensional properties.

INTRODUCTION

Water chestnut (*Trapa Natans*) belonging to the monogeneric family trapaceae. Water chestnut had been introduced as an ornamental plant by Europe. Its spreading is limited because of the large sinking nuts, but the fruit has persisted and spread northern, central and western states. It is aquatic angiospermic free floating plant which generally grown naturally in fresh water saturated land, marshes, ponds, bogs, sluggish reaches of river, swamps and brackish reaches of estuaries in both tropical and subtropical countries. It is one of the most important underutilized agricultural fruit crops. This fruit crops grow during the warmer part of the year and die out with the start of severe winter (Hummel and Kiviat, 2004).

The most widely cultivated species have been referred to as *Trapa bispinosa or Trapa Natans* L. It is commonly known as Singhara, 'Shinghoda' in Gujarati, 'Paniphal' in Bengali, 'Pani Singhara' in Oriya and 'Kubyakam' in Telgu. It is an excellent source of starch and can be used as a substitute for other starchy food materials like potato, corn and wheat. It is also known as poor man's food. Only five percent of its produce is consumed as raw and 95 percent is processed.

In India, it's popularly known as Singhara and is widely cultivated in lakes, river and freshwater habitats. The cultivation practices are mainly done in different part of the country like Punjab, Bihar, Madhya Pradesh, Uttar Pradesh, Chennai, Mumbai and also all the major water bodies of Jammu and Kashmir, particularly in wular lake, which is Asia's largest fresh water lake. Average production of water chestnut from this lake is about 4000-5000 MT (Syed *et al*., 2018). In Madhya Pradesh the crop occupies 210 ha land with an average yield of 1000 kg/ha. Two varieties of Water Chestnut are now generally recognized one is thorny and another one is thorn less. Water chestnut should not be confused with the unrelated Chinese water chestnut (*Eleocharis dulcis*) (family *Cyperaceae*), a spikes edge with an edible tuber that is commonly used in Chinese cuisine.

The interesting feature of water chestnut is the color and shape of its outer cover in which the kernel is encased. The water chestnut fruit is covered with a thick jet-black outer pericarp shaped like a horn protruding from the head of buffalo. The outer cover is hard, which make it difficult to peel off to obtain the internal white fruit. Its seeds are called as recalcitrant which means they lose viability under reduced moisture and low temperature conditions and cannot be stored in gene banks (King and Roberts, 1980).

The fruit is used as a substitute for cereal in the Indian subcontinent during fasting days. In northern state of India, the harvested water chestnuts drying over mud Chulha up to 10-12 days, after that performing grinding to make flour. Rest of the place, mostly the drying of whole water chestnut is generally done by the "sun drying" method. Followed by roasting in the sand in large iron pans which account huge losses of time results less kernel recovery, low flour yield and in addition, produces the product of low quality. The dried flour is very low in fat and easily digestible and is helpful for dieting. Its flour is consumed in the form of sweet dish and for making bread, puri, halwa on several religious occasions. Besides, it has considerable importance in the manufacturing of product like biscuits; infants milk formula, starch as well as alcohol. Thus, this flour is gluten free and can be good replacement for wheat flour due to celiac disease caused by gluten intolerance.

Perishable nature of water chestnut is the main reason for its limited industrial applications and their utilizations. Water chestnut kernel is delicious contains starch in abundance and very low amount of fats (Gani *et al*., 2010).

Singhara flour is a rich source of carbohydrate, proteins, fiber, potassium, calcium, phosphorous, iron, vitamins and polyphenols (Vaughan and Geissler, 1997; Lee and Hwang, 1998; Singh *et al*., 2011; Alfasane *et al*., 2011). They are low in sodium and fat which is almost negligible. If we count calorie single cup of water chestnut kernel slices holds about 130 calories.

Chestnut is used to overcome over malnutrition and rich source of starch. The gluten free flour can be used for making bread, cookies, snacks, pasta also used as thickeners, stabilizer, adhesive and act as binding agent in various sweets (Borges *et al*., 2007).

In most of the part of India, water chestnut is presently being consumed by the people as dried nut and is being sold as nut or dehulled nut in the market which does not help the farmers in getting their returns to the extent it should have been. Also, the flour of the water chestnut is being used for diabetic patients and in great demand in pharmaceutical industries within and outside the India.

In broader sense objectives were formulated to improve kernel recovery, yield by reducing the losses of edible part and quality of water chestnut flour. It is prime importance to understand the chemistry and the structure of starch. Therefore, an opportunity exists to conduct detailed study of hot water treatment, residence time for optimization of pretreatment of water chestnut for higher recovery and quality of flour.

Physicochemical properties of fresh water chestnut. Majumdar & Jana (1977) did physicochemical analyses of water chestnut fruit to provide fundamental data for water chestnut processing and product development. It was found that minimally processed fresh products have relatively short life because of large amount of tissue disruption and increased metabolism which results in a very rapid onset of enzymatic browning.

Singh *et al*. (2011) studied physical properties of water chestnut flour in which bulk density (g/ml) of loose sample was found to be 0.696 and thereof for packed sample was 0.994. Similarly, water binding capacity (g/100g; dwb) was found 89.78 and oil binding capacity (g/100g; dwb) was found 60.41.

Bala *et al.* (2015) studied physical properties of water chestnut flour for evaluating functional and sensory properties of cookies prepared from wheat flour supplemented with cassava and water chestnut flour is given in Table 1.

Table 1: Physical properties of water chestnut flour.

Constituents	Values
Water binding capacity (g/100g; dwb)	90.42 – 93.04
Oil binding capacity (g/100g; dwb)	62.15 – 62.55
Swelling power (g/g)	10.27 –12.29
Solubility (%)	10.20 –13.06
Bulk density (g/ml) (Loose)	0.59 –0.79
Bulk density (g/ml) (Packed)	0.96 –1.02
L*	76.79 – 80.09
a*	4.29 – 6.37
b*	12.86 – 13.12
ΔE	57.19 – 58.55

Mushtaq *et al.* (2020a) studied classification of water chestnuts, their dimensional properties and their correlation analysis. It was observed that the mean value of principal dimensions like length, width and thickness of whole water chestnut and water chestnut kernels (Table 2). Equivalent diameter (De), geometric diameter (Dg), arithmetic diameter (Da), sphericity (%), area of transverse surface (mm^2), aspect ratio, volume (mm^3) and surface area (mm^2) was determined from the data obtained from the tuber dimensions. Also, reported that data generated during the study will help in designing post harvest handling equipments for water chestnut in future.

Table 2: Dimensional properties of whole water chestnut and kernels.

Dimensional properties Grade	Length Mm		Width mm		Thickness mm	
	Whole water chestnut	Water chestnut kernels	Whole water chestnut	Water chestnut kernels	Whole water chestnut	Water chestnut kernels
I	≤ 30	≤ 18	≤ 23	≤ 13	≤ 9	≤ 7
II	30-35	18-24	23-27	13-16	9-12	7-10
III	35-40	24-30	27-31	16-19	12-15	10-13
IV	40-45	30-36	31-35	19-22	15-18	13-16
V	> 45	> 36	> 35	> 22	> 18	> 16

MATERIALS

The research work was undertaken at Department of Process and Food Engineering, College of Agricultural Engineering and Technology, AAU, Godhra and Polytechnic in Agricultural Engineering, AAU, Dahod, Gujarat.

Fully matured fresh water chestnut red variety (*Trapa natan*) was procured from local market of Dahod, Gujarat. Examined each batch of water chestnut and care was taken to have water chestnut should free from any bruised. The water chestnut corms were then washed under running portable water to remove surface dirt and then air dried.

Dimensional Properties: Whole water chestnuts as well as kernels selected randomly were evaluated for principal dimensions. Three major perpendicular dimensions of 100 fresh whole water chestnut fruits as well as kernels were measured from the graded samples. These principal dimensions length, width and thickness were measured using dial caliper having an accuracy of 0.01 mm (Plate 1 & 2). The derived dimensional properties like equivalent diameter, geometric diameter, arithmetic diameter, sphericity, area of transverse surface, aspect ratio, volume and surface area of whole water chestnut as well as kernels were calculated from principal dimensional values using the following relationships (Mushtaq *et al*., 2020b).

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

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

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

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

Area of transverse surface (mm^2) = $\left[\frac{\pi}{4}\right] TW$

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

Volume (mm^3) = $0.25\left[\frac{\pi}{6} L\ (W+T)^2\right]$

Surface area (mm^2) = $\pi \times D_g^2$

Where,

L – Length
W – Width
T – Thickness
D_a – Arithmetic diameter
D_g – Geometric diameter
D_e – Equivalent diameter

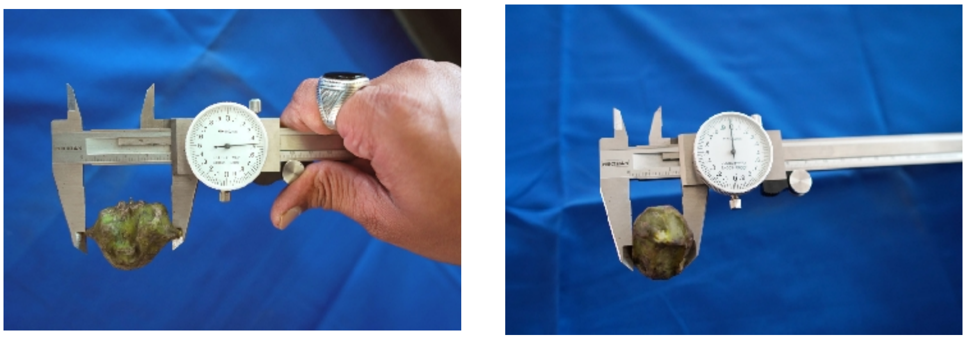

Plate 1: Measurement of length and width of whole water chestnut fruits.

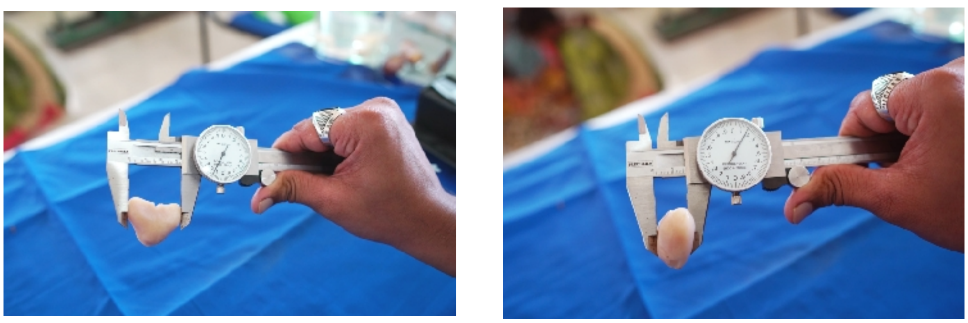

Plate 2: Measurement of length and width of water chestnut kernels.

Bulk density: Bulk density was determined by filling the samples into square container (300 × 300 × 300 mm^3) to overflow and removing excess sample by rolling glass rod on edge of square container without compacting the whole water chestnut and kernels simultaneously (Plate 3). To achieve uniform bulk density, the measuring container was tapped to consolidate as reported by Balasubramanian & Viswanathan (2010). Five replications were taken and their average value was worked out.
Bulk density can be calculated as ratio of measured mass and bulk volume.

$$\text{Bulk density} = \frac{\text{Mass of sample (kg)}}{\text{Bulk volume (m}^3\text{)}}$$

Plate 3: Measurment of bulk density of whole water chestnut and kernels.

Hardness. Hardness of whole water chestnut and kernels was measured using hand held pocket penetrometer in terms of pressure required to pierce the fruit. For the evaluation of hardness, 100 fruits were selected randomly from the bulk sample. Care was taken to avoid fruit free from defects such as pest or disease damage. Repeated the process on the opposite side of the same fruits and all the experiments were carried out in five times (Plate 4).

Plate 4: Hardness measurement of whole water chestnut and kernels.

Standardization of Hot Water Treatment for Water Chestnut: Pressure vessels were designed and fabricated using stainless steel material having capacity of 90 lit. Pressure vessel provided with steam release valve, pressure gauge, RTD sensor, hot water drain valve and handle placed on MS angle frame stand with tilting assembly for easy handling.

In each pressure vessels 30 kg of fresh whole water chestnut sample with 45 liter water was kept, inside pressure was designed to build up to 2 kg/cm^2 and at this pressure corresponding temperature was rise to 130 ºC, required temperature for standardization of WWC was 90 ºC.

Whole water chestnuts were subjected to precondition by keeping Water chestnut: Water ratio 1:1.5 and kept water temperature about 87.85 ºC as suggested by Syed *et al.*, (2019). Hot water treatment was given to the samples for 30, 60 and 90 min and then samples kept inside the vessels at different time duration i.e., 60, 120 and 180 min as residence time.

Plate 5: Pressure vessels assembly with RTD controller.

METHODOLOGY

Pretreatment to water chestnut is an important practice to harden the endosperm and to make it translucent. The existing pretreatment practice in localized area is to heat water chestnut in open atmospheric condition for more than 2 h keeping Water: Water chestnut ratio of 0.25:1.00 and temperature about 80-85 ºC followed by shed drying for 3-4 days. This practice is very time consuming as well as non uniform cooking leads to less kernel recovery. Hot water pretreatment gelatinize the starch present inside the endosperm and make kernel hard. Hence, pretreatment to water chestnut is very important to get higher decorming efficiency with minimum breakage. Therefore, pretreatment of WWC is required to be standardized. The important process variables that influence the extent of gelatinization during pretreatment of water chestnuts are given below.

Table 3: Treatment combination of HWT and RT on WWC.

Sr.No.	Hot water treatment (HWT) (min)	Residence time (RT) (min)
1.	30	60
		120
		180
2.	60	60
		120
		180
3.	90	60
		120
		180
4.	Control (120)*	180*

*Traditional practices used for water chestnut

Observations

i	Physical parameters	:	Length, Width, Thickness and Bulk density
ii	Textural Property	:	Hardness
iii	Statistical design Repetitions	: :	Completely Randomized Design (CRD) 04
Total experiments = 3 (HWT) X 3 (RT) + 1 (Control) X 4 (Repetitions) = 40			

This pretreatment process fills the void spaces and seals the internal cracks of the endosperm with gelatinized starch and leads to enhance kernels recovery by minimizing surface fissures and kernels damage. Best treatment combinations will be used for the further experiments to optimize decorming machine parameters.

Plate 6: Unloading cooked water chestnut by tilting the pressure vessel.

RESULTS AND DISCUSSION

A. Dimensional properties of whole water chestnut (WWC)

Standardization of hot water treatment and residence time was needed brief study of physical properties of whole water chestnut. Average weight of whole water chestnut (WWC) and water chestnut kernels (WCK) after manual decorming were found to be 27.42 g and 12.14 g, respectively. The ratio of kernel to corm shell was calculated as 0.79:1.00.

The derived dimensional properties like equivalent diameter, geometric diameter, arithmetic diameter, sphericity, area of transverse surface, aspect ratio, volume and surface area of WWC as well as kernels were calculated from principal dimensional values length (L), width (W) and thickness (T) of graded water chestnut are depicted in Table 4.

Table 4: Dimensional properties of WWC

Parameters	Range	Mean and S.D. (n=100)
Length (mm)	43.17 – 63.50	52.12 ± 5.09
Width (mm)	32.12 – 42.66	36.43 ± 2.38
Thickness (mm)	15.05 – 23.52	18.19 ± 1.73
Equivalent Diameter (De) (mm)	30.13 – 38.95	33.84 ± 1.95
Geometric Diameter (Dg) (mm)	28.53 – 37.21	32.50 ± 1.91
Arithmetic Diameter (Da) (mm)	31.46 – 41.50	35.58 ± 2.26
Sphericity (%)	53.86 – 75.15	62.68 ± 4.14
Area of transverse Surface (mm^2)	403.81–741.86	521.06 ± 65.23
Aspect ratio	0.57 – 0.86	0.70 ± 0.07
Volume (mm^3)	14315.82 – 30929.51	20496.62 ± 3597.39
Surface area (mm^2)	2557.64 – 4350.14	3330.04 ± 393.08
Hardness (N)	29.17 – 61.22	47 ±7.37

The principal dimensions length, width and thickness of WWC were varied between 43.17 to 63.50 mm, 32.12 to 42.66 mm and 15.05 to 23.52 mm, respectively and their mean values were found to be 52.12 ± 5.09 mm, 36.43 ± 2.38 mm and 18.19 ± 1.73 mm, respectively.

The derived dimensional properties *viz.* equivalent diameter, geometric diameter, arithmetic diameter, sphericity, area of transverse surface, aspect ratio and surface area of WWC ranged between 30.13 to 38.95 mm, 28.53 to 37.21 mm, 31.46 to 41.50 mm, 53.86 to 75.15%, 403.81 to 741.86 mm^2, 0.57 to 0.86, 2557.64 to 4350.14 mm^2 and the mean values of the same were found to be 33.84 ± 1.95 mm, 32.50 ± 1.91 mm, 35.58 ± 2.26 mm, 62.48 ± 4.14 %, 521.06 ± 65.23 mm^2, 0.70 ± 0.07, 3330.04 ± 393.08 mm^2, respectively.

Sphericity of whole water chestnut was ranged between 53.86 to 75.15 % which is close to 100 % indicates perfect spherical shape. The lower values of sphericity obtained in case of whole water chestnuts were due to their triangular and irregular shapes Mushtaq *et al*., (2020a). Aspect ratio was ranged from 0.57 to 0.86 which gives an idea about the oblong shape of the material and indicates that water chestnuts have a tendency to slide rather than roll on flat surfaces. Sphericity and aspect ratio of the whole water chestnut are important parameters to be considered before designing hopper and discharging chutes of water chestnut decorming machine. Volume of WWC was ranged between 14315.82 to 30929.51 mm^3 and mean value was found to be 20496.62 ± 3597.39 mm^3.

Bulk density and hardness were found in the range between 717.50 to 840.14 kg/m^3 and 29.17 to 61.22 N. Mean value of the same were 795.73 ± 32.46 kg/m^3 and 47 ± 7.37 N, respectively.

B. Dimensional properties of water chestnut kernels (WCK)

Length, width and thickness of WCK were varied between 37.01 to 56.47 mm, 23.2 to 29.54 mm and 12.36 to 21.23 mm, respectively. The mean values of the same were 44.67 ± 4.83 mm, 27.03 ± 0.92 mm and 16.34 ± 1.71 mm, respectively. The dimensional properties of WWC are presented in Table 5.

The derived dimensional properties *viz.* equivalent diameter, geometric diameter, arithmetic diameter, sphericity, area of transverse surface, aspect ratio, volume and surface area of WCK were ranged between 24.69 to 30.97 mm, 23.98 to 30.50 mm, 25.78 to 34.12 mm, 49.06 to 72.18 %, 347.26 to 485.76 mm^2, 0.49 to 0.76, 1805.86 to 2922.46 mm^2 and their mean values were found to be 27.56 ± 1.41 mm, 26.96 ± 1.50 mm, 29.35 ± 1.86 mm, 60.77 ± 4.49 (%), 347.26 ± 39.97 mm^2, 0.611 ± 0.06, 2291.36 ± 256.16 mm^2 , respectively.

Sphericity and aspect ratio were ranged between 49.06 to 72.18 % and 0.49 to 0.76 which is close to 100 % indicates perfect spherical shape. Volume of WCK were ranges between 7836.25 to 15557.11 mm^3, and mean value was found to be 11052.14 ± 1717.37 mm^3. Similar results have been reported by Singh *et al*., (2010); Walde and Mishra, (2016); Mushtaq *et al*., (2020).

Bulk density and hardness of WCK were found between 840.42 to 990 kg/m^3 and 22.48 to 55.46 N, respectively and their mean values were found to be 914.14 ± 0.04 kg/m^3 and 36.14 ± 7.06 N, respectively. Similar results were found by Singh *et al.*, (2010) and Mushtaq *et al*., (2020).

Table 5: Dimensional properties of WCK.

Parameters	Range	Mean and S.D. (n=100)
Length (mm)	37.01 – 56.47	44.67 ± 4.83
Width (mm)	23.2 – 29.54	27.03 ± 0.92
Thickness (mm)	12.36 – 21.23	16.34 ± 1.71
Equivalent Diameter (De) (mm)	24.69 – 30.97	27.56 ± 1.41
Geometric Diameter (Dg) (mm)	23.98 – 30.50	26.96 ± 1.50
Arithmetic Diameter (Da) (mm)	25.78 – 34.12	29.35 ± 1.86
Sphericity (%)	49.06 – 72.18	60.77 ± 4.49
Area of transverse Surface (mm^2)	347.26–485.76	347.26 ± 39.97
Aspect ratio	0.49 – 0.76	0.611 ± 0.06
Volume (mm^3)	7836.25– 15557.11	11052.14 ± 1717.37
Surface area (mm^2)	1805.86 – 2922.46	2291.36 ± 256.16
Hardness (N)	22.48 – 55.46 N	36.1339 ±7.06

C. Effect of HWT and RT on length of WCK

At different combination of duration of hot water treatment (HWT) and residence time (RT), changes in lengths of WCK are shown in Fig.1. Mean value of WCK (Control) length was 44.37 mm. After treatment highest changes in length of WCK 45.54 mm for 30 min HWT and 120 min RT. However, lowest length 41.64 was observed when water chestnut treated with hot water for 30 min and 180 min residence time. Similarly, highest and lowest changes in length for 60 min HWT was found 49.63 mm and 40.46 mm at 120 min and 180 min RT. Whereas, Overall lowest value 39.86 mm of length was found at 90 min HWT and 180 min RT, respectively.

Data generated during experiments were analysed statistically. It can be observed that F_{Cal} values for hot water treatment time and residence time are 11.755 and 3.809 at F_{Tab} values 3.350 and 3.350 against CD (Critical Difference) value 2.368 and 2.368, respectively indicating the change in length was significant.

The effect of HWT and RT on mean value of length was found significant while interactive effect between HWT and RT was not significant. The treatment H_2RT_2 (HWT 60 min and RT 120 min) has given significantly higher length 49.63 mm followed by H_2RT_1 and H_1RT_2. Increase in length was due to the absorption of water by water chestnut during hot water treatment and residence times allow to coagulate kernels and decreased in length may be due to the vaporization of free water from water chestnut kernels at prolonged residence time. Similar results were obtained by Singh *et al*., (2010); Syed *et al*., (2019).

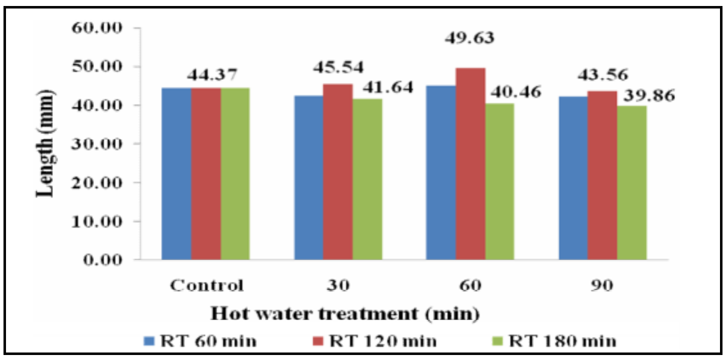

Fig. 1. Effect of HWT time and RT on length of WCK.

D. Effect of HWT and RT on width of WCK

Water chestnut kernel control sample width was 24.03 mm. After treatment highest and lowest changes in width for 30 min HWT were found 24.70 and 22.44 mm for 120 and 180 min RT. However, highest and lowest widths for 60 min HWT were observed 25.90 and 23.32 mm for 120 and 180 min RT. While, 90 min HWT gives highest and lowest widths were 23.61and 22.70 mm for 60 min and 180 min RT, respectively (Fig. 2).

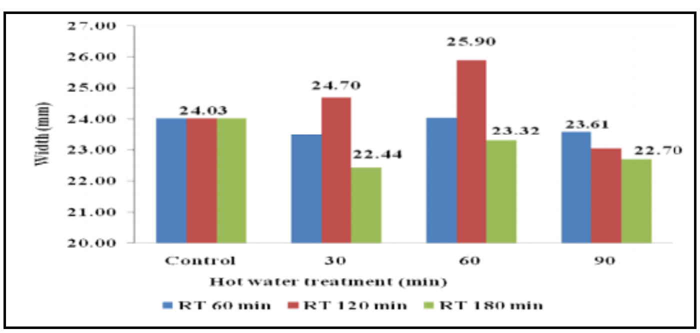

Fig. 2. Effect of HWT time and RT on width of WCK.

It can be observed that F_{Cal} values for hot water treatment time and residence time were 4.809 and 8.252 at F_{Tab} values 3.350 and 3.350 against CD value 0.8750 and 0.8750, respectively indicating the change in width was significant (P<0.05).
The effect of hot water treatment and residence time on width was significant (P<0.05). The interaction effect between HWT and RT was not significant; it indicates that there is no combine effect of HWT and RT on width. The treatment H_2RT_2 (HWT 60 min and RT 120 min) has given significantly higher width 25.90 mm followed by H_1RT_2 and H_2RT_1. Increase in width is due to water absorption by water chestnut during pretreatment and decreased in width may be due to the vaporization of free water from water chestnut kernels at prolonged residence time. The results are covenant with Syed *et al*., (2019).

E. Effect of HWT and RT on thickness of WCK
Water chestnut kernel control sample thickness was 14.88 mm. After treatment highest and lowest changes in thickness for 30 min HWT were found 17.35 and 14.96 mm for 120 and 180 min RT. However, highest and lowest thicknesses for 60 min HWT were observed 17.91 and 15.56 mm for 120 and 180 min RT. While, 90 min HWT gives highest and lowest thicknesses were 16.05 and 15.32 mm for 60 min and 180 min RT, respectively (Fig. 3).

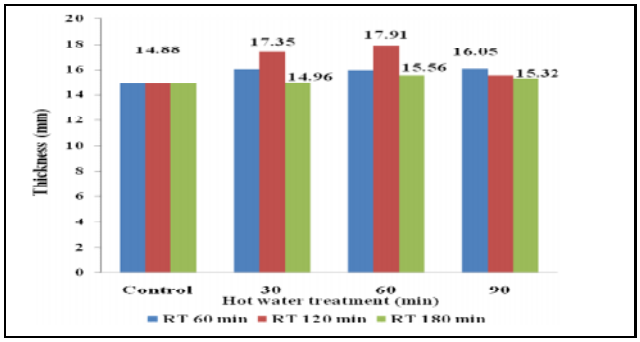

Fig. 3. Effect of HWT time and RT on thickness of WCK.

It can be observed that F_{Cal} values for hot water treatment time and residence time are 2.745 and 11.078 at F_{Tab} values 3.350 and 3.350 against CD value 0.7250 and 1.2550, respectively indicating the change in thickness is significant (P<0.05).
The effect of hot water treatment and residence time on thickness at 60 min HWT and RT of 120 min as examine highest mean value 16.47 mm and 16.94 mm, respectively. Also the interaction effect between HWT and RT was significant (P<0.05). The treatment H_2RT_2 (HWT 60 min and RT 120 min) has given significantly higher thickness 17.91 mm followed by H_1RT_2. The results are agreement with Walde and Mishra (2016); Syed *et al*., (2019).

F. Effect of HWT and RT on bulk density of WCK
The kernels bulk density was significantly decreased and ranged between 904.7 kg/m^3 to 842.2 kg/m^3. At hot water treatment 30 min and residence time 60 min maximum bulk density (904.7 kg/m^3) was observed while minimum bulk density was found 842.2 kg/m^3 at 60 min HWT and 120 min RT (Fig. 4). The decrease in bulk density was because of increase in volume due to moisture absorption by water chestnut and kernels. Temperature above gelatinization enhance water uptake rate by breaking the intermolecular hydrogen bonds between amylase and amylopectin fractions. Further increased in 90 min HWT and 180 min RT, the principal dimensions of water chestnut kernels were decreased resulted in decreased in volume.

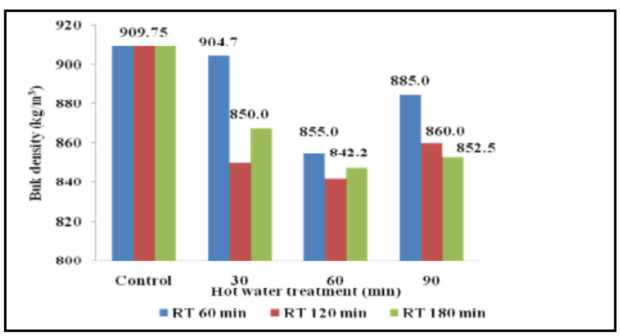

Fig. 4. Effect of HWT time and RT on bulk density of WCK.

The effect of hot water treatment and residence time on bulk density was significant (P<0.05) had maximum bulk density at mean values of HWT and RT mean 880.8 and 884.2 kg/m^3. The interaction effect between HWT and RT was not significant. The treatment H_1RT_1 (HWT 30 min and RT 60 min) has given significantly higher bulk density 904.7 kg/m^3 followed by H_1RT_3 and H_3RT_1. Similar results were found by Syed *et al*., (2019).

G. Effect of HWT and RT on hardness of WWC
The initial hardness of water chestnut kernel (Control) was 36.14 N and was significantly increased to 53.05 N at 30 min HWT and 60 min RT (Fig. 5). For higher decorming efficiency of water chestnut and higher kernels recovery, force required to scratch WWC should be minimum. It can be observed from Fig. 5. After treatment highest and lowest changes in hardness for 30 min HWT were found 53.05 and 37.75 N for 60 and 180 min RT. However, highest and lowest hardness for 60 min HWT were observed 33.95 and 24.89 N for 60 and 120 min RT. While, 90 min HWT gives highest and lowest hardness were 38.74 and 25.50 N for 180 min and 60 min RT, respectively.

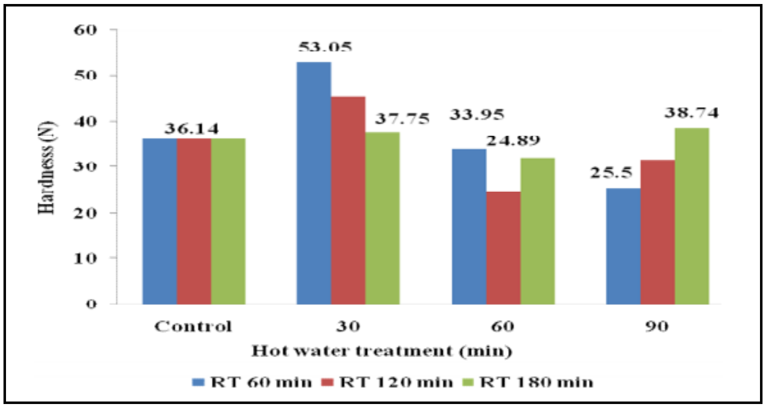

Fig. 5. Effect of HWT time and RT on hardness of WWC.

It can be observed that F_{Cal} values for hot water treatment time, residence time and interactions were 131.973, 5.718 and 37.136 at F_{tab} values 3.350, 3.350 and 2.730 against CD value 2.0980, 2.0980 and 3.6330, respectively which indicates the change in hardness was significant.

The interaction effect between HWT and RT was found significant. The treatment H_1RT_1 (HWT 30 min and RT 60 min) has given significantly highest hardness 53.05 N followed by H_1RT_2. Increase in hardness at lower hot water treatment time is due to absorption of moisture and improper cooking of water chestnut kernels. Almost, similar results have been reported for cashew nut kernels by Pawar *et al*., (2017). Messia *et al*., (2012) reported that parboiling promoted compactness in kernels and increased the decortication efficiency in case of sorghum and milling yield in emmer yield, respectively.

CONCLUSION

After grading whole water chestnut, pretreatments were given to graded sample. Hot water treatment duration was kept 30, 60 and 90 min and then sample were kept for 60,120 and 180 min as residence time. Effects of treatment combination i.e. HWT and RT on dimensional properties of WCK were observed to standardize the pretreatment parameters. From all the observation, it was found that if the graded sample treated for 60 min in hot water and then kept it for 120 min as residence time gave good quality of water chestnut kernels i.e. length, width, thickness, bulk density and hardness are 49.63 mm, 25.90 mm, 17.91 mm, 842.2 kg/m^3 and 24.89 N respectively. The outcome of this present study will give valuable insight for designing post harvest handling system for water chestnut.

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