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Studies on physicochemical properties and effect of pretreatment on drying characteristics of water chestnut

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Abstract

Water chestnut (*Trapa bispinosa* Roxb.), locally known as singhara – an edible aquatic angiosperm covered with a thick jet-black hard outer cover was obtained from local pond, Lucknow, Uttar Pradesh, India. It is commonly consumed after steaming once the outer cover gets soften and inside white meat is cooked. Meat is good source of protein (8.24%, d.b.) and carbohydrate (84.8%) which is usually eaten as a snack or as an ingredient in other foods and also during fasting as an ethnic food. The present studies were carried to see the effect of pre-treatments viz., citric acid (1%, w/v solution); blanching followed by 300 ppm KMS; fermented milk i.e. curd; fermented whey i.e. buttermilk; and salt solution (4%, w/v) for 8h and then samples were dried in cabinet tray dryer. The pretreatment of buttermilk on water chestnut has induced a small effect for faster evaporation of moisture and resulted in faster drying with diffusivity of (1.353×10^{-9} m^2/s) as compared to control (1.260×10^{-9} m^2/s). It was found that the average particle size of water chestnut powder in dried state was of 65.82 micron (69%) and 39.54 micron in dispersed aqueous phase.

Introduction

Water chestnut (*Trapa natans* L. var. *bispinosa* Roxburgh) is an edible aquatic angiosperm locally known as "Singhara". It is one of the important annual aquatic warm season crops. It is a floating (submerged rooted) plant, found commonly on the water surface of lakes, tanks and pools throughout India especially in Punjab, Bihar, Uttar Pradesh, Madhya Pradesh, Tamilnadu, Maharashtra and in some parts of Uttarakhand and similar countries (Puste, 2004; Takano and Kadono, 2005). In India the two popular species *Trapa bispinosa* and *Trapa quadrispinosa* of water chestnut are widely cultivated. Water chestnut is an important commodity in food industry because of its unique taste (Parker and Waldron, 1995). Water chestnuts can be used in a variety of recipes because they have a starchy taste that is fairly neutral. Some people claim that their flavour is similar to a bland nut. Water chestnuts also have a firm and crispy texture, which adds to their appeal as an ingredient in stir-fries, salads, or any meals where the vegetables to be used must have a crunchy consistency. The fruits are eaten raw at tender stage and sometimes after boiling and roasting. It is consumed mainly in the form of cooked vegetable, flour or in the shape of sweet dishes of many kinds. It compares well with other foods and is a good source of carbohydrates, proteins and essential minerals. The dark-brown corms (whole fruit) are peeled before cooking or canning. The bulk of the edible region consists of starch-rich, thin walled storage parenchyma similar in appearance to potato, interspersed with vascular strands. However, in contrast to potato, water chestnut is notable for its ability to maintain a firm and crunchy texture after considerable heat treatment during canning or cooking. This property is attributed to the lack of cell separation during cooking (Loh *et al*., 1982; Klockeman *et al*., 1991). Usually, the fruits are washed, peeled, sliced and packaged, before commercially sold. However, minimally processed fresh products have relatively short shelf life, because of large amount of tissue disruption and increased metabolism that lead to rapid onset of enzymatic browning.

Trapa bispinosa is a floating aquatic herb, one of the medicinal plants that have been used as a nerve tonic from time immemorial (Ambikar *et al*., 2010). The acrid juice is used for diarrhoea and dysentery. The fruits are used as intestinal astringent, aphrodisiac, anti-inflammatory, antileprotic, in urinary discharges, fractures, sore throat, bronchitis and anaemia

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(Kirtikar and Basu, 1993), free radical scavenging activity (Kim *et al*., 1997), hepatoprotective activity (Kar *et al*., 2004), antitumor and antioxidant activity (Irikura *et al*., 1972; Song *et al*., 2007)

In view of the consumers demand for natural foods having good therapeutic values, water chestnut extends its high values in many aspects of therapeutic food. The high consumption values of the fresh fruit are probably linked to the high nutritional and organoleptic value, and also to the increasing interest of the consumers towards organic products. Lee and Hwang (1998); Singh *et al*. (2010) studied physicochemical properties to provide basic data for water chestnut processing and product development. In order to have different products from water chestnut, it is essentially the kernels are to be dried up for longer storage period with some treatment. Drying and moisture diffusivity theories have been reviewed by Majumdar (1980) for numerous food materials which is also regarded as one of the major preservation process in food and chemical industries in the globe time immemorial. Wang and Sastry (1997) reported that blanching pretreatment has resulted in increase in ionic content of the solids and hence electrical conductivity by increasing the blanching time of water chestnut. As vegetable tissues are heated, structural changes like cell wall breakdown, tissue damage, increase in mobile moisture and softening occurs which in turn increase in electrical conductivity in ohmic heating and higher evaporation rate. Jain *et al.* (2012) reported that fruit kernels are juicy and crisp when raw whereas when it is cooked, flesh soften but still remains crunchy.

It is worth to mention that pre-treatments of many fruits and vegetables before drying in one form or other viz., washing in water, KMS, sugar, salt either alone or in combination inhibit enzymatic browning, enhancing colour, flavour and texture retention (Singh *et al*., 2008). It was reported by Walde *et al.* (2001) that curd and whey treated bitter gourd when dried were found to have encouraging results with regards to maintaining colour, flavour and texture. Therefore, the present studies have been undertaken to find the effect of various treatments on dehydration characteristics of water chestnut slices.

Materials and Methods

Procurement of raw material

Fresh water chestnut (*Trapa bispinosa* Roxb.) fruits were purchased from the local ponds of Lucknow, Uttar Pradesh, India. The fruits were washed thoroughly with tap water; excessive water was drained and further stored at refrigerated temperature (4°C) till further use. Other chemicals used were of AR grade and double distilled water was used for the analysis.

Physico-chemical properties

Based on the visual experience, size and maturity, grading of the whole fruits were made to three categories viz., under mature, matured and over matured.

Physical measurement

Length, width and thickness were measured at nine different points to an accuracy of 0.02 and 0.01 mm using a vernier callipers and micrometre (Mitutoyo, Japan) respectively to have a mean average of all measurement.

Density

Bulk density was determined with 1L volumetric (10 cm dia and 10 cm height) grain measuring cylinder. True density was measured using water displacement method with same material used for bulk density for 1L volume measuring cylinder.

Proximate chemical analysis

The pH was measured by digital glass electrode pH meter (Model Control Dynamic, India).Total soluble solids (^{0}brix) of the sample, the acidity, total sugars, reducing sugar and starch of the samples were estimated as per the procedure of Ranganna (2002). The moisture and ash content were calculated using AOAC (2006) method. The moisture was converted to dry weight basis and reported as kg of moisture/ kg of dry matter in fitting the graph and equations.

Alcohol insoluble solids were determined by boiling 20 g water chestnut pulp with 300 ml of 80% aqueous alcohol and simmering for 30 minutes, filtering, washing the residue with 80% alcohol and drying the residue at 100°C for 24 h (Hart and Fisher, 1971) and expressed in percentage by weight.

Dehydration kinetics of water chestnut

Sample preparation

Wholesome matured fresh fruits were selected and peeled manually after cutting two sides by sharp knife. The peeled kernels were sliced with thickness of 3.5+0.4 mm. The whole lot of cut slices were immediately dipped into water containing 0.5% KMS for 20 min till given further pre-treatment. The slices were determined for its initial moisture content and were found to be 84.49% on wet basis (AOAC, 2006).

Table 1. Physical Characteristics of fresh whole fruit and peeled Water Chestnut kernel*

Maturity	Avg. Length (mm)	Avg. height (mm)	Avg. Thickness (mm)	L/H Ratio	Average weight (g)	Average volume (ml)	Density
Fresh whole fruit of water chestnut							
Under mature	28.78	26.43	14.12	1.089	9.498	9.45	0.995
Mature	32.43	30.22	14.96	1.073	12.564	12.2	1.030
Over mature	34.16	33.34	16.04	1.025	14.218	12.5	1.137
Fresh peeled water chestnut kernel							
Under mature	24.70	21.14	12.86	1.168	7.241	7.20	1.006
Mature	26.23	23.08	14.27	1.136	8.396	8.28	1.014
Over mature	27.69	25.31	14.88	1.094	10.162	9.95	1.021

*Each value represents the average of triplicate

Pre-treatment of Water chestnut slices

The individual lot of 150 g slices were subjected to different pre-treatments viz., citric acid (1%) solution, blanching followed by 300 ppm KMS, fermented milk i.e. curd, churned diluted fermented milk i.e. buttermilk and salt solution (4%, w/v) with a control one. All the pre-treatments were given for 8h and then were noted with its gained or lost weight after draining the liquid and wiping with blotted tissue paper.

Drying kinetics studies

All the six samples after its pre-treatment and draining, known weight of samples were taken to six perforated trays one sample in each tray in cabinet tray dryer fitted with PID control (M/s. Magumps, Dadar, Mumbai, India). The initial weights were noted and subjected to drying at 55+2˚C. The initial temperature was maintained at 55˚C for 1h and then gradually raised to 60+2˚C till complete dehydration. The reading were taken at regular interval of 10, 15, 30 min for first, second and subsequent hour, respectively. Since the initial drying rate was faster, the trays were circulated from top to bottom at each reading interval so as to maintain uniform air flow on drying of all samples.

Particle size analysis of water chestnut powder

The dried water chestnuts without pretreatment were subjected to laboratory grinder to make fine powder. This powder was analysed for particle size analysis by Microtrac (Turbotrac) S3500 particle size analyser having flex software, Bluewave, Florida, USA which gives the percentile fractionation as well as average particle size.

Table 2. Chemical composition of peeled water chestnut*

Parameters	Under mature	Mature	Over mature
Moisture	88.4	84.5	76.2
Ash	0.52	0.623	0.704
Reducing Sugar	3.62	3.14	2.43
Total Sugar	4.9	4.2	3.8
Acidity (as % anhydrous citric acid)	0.126	0.152	0.168
Starch (%)	2.74	5.32	9.48
Alcohol insoluble solids (% AIS)	7.2	10.32	20.54

*Each value represents the average of triplicate

Results and Discussion

Physical analysis

It is revealed from the table 1 that average weight of under matured, matured and over matured whole water chestnut varies from 9.5 to 14.2 g; average volume varies from 9.5 to 12.5 ml and density in the range of 0.995 to 1.137 which is in agreement with the Rodriguez *et al.* (1964). The water chestnut is in triangular bull's head shape and therefore width varies from top to bottom wherein the average width at broader end was 37, 42, and 46 mm and lower end 19, 24 and 26 mm for under matured, matured and over matured whole fruits respectively; whereas height varies from 26 to 34 mm depending upon its maturity. The thickness was found to be from 14 to 16 mm.

The peeled water chestnut fresh fruits dimensions are mentioned in table 1 wherein the average width at broader end was 33, 36, and 37 mm and lower end 15, 17 and 19 mm for under matured, matured and over matured peeled water chestnut fruits respectively;

Table 3. Polynomial fit coefficient, regression and diffusivity coefficient for drying of Water chestnut

Treatments	Regression R^2	Drying curve polynomial equation fit			Diffusivity coefficient (m^2/s)
		c_0	c_1	c_2	
Control	0.9947	1.1477	-0.1523	0.0050	1.260 x10^{-9}
Citric acid	0.9928	1.1721	-0.1563	0.0054	0.879 x10^{-9}
Salt	0.9946	1.1836	-0.1752	0.0065	1.161 x10^{-9}
Curd	0.9875	1.0705	-0.1513	0.0057	0.789 x10^{-9}
Butter milk	0.9887	1.0918	-0.1772	0.0072	1.353 x10^{-9}
Blanched	0.9788	1.0389	-0.1449	0.0053	0.719 x10^{-9}

c_0 and c_1: constant (%db/s); c_2: position in the sample where the moisture content (m/s^2)

whereas height varies from 21 to 25 mm depending upon its maturity. The thickness was found to be in the range of from 13 to 15 mm. The dimensions measured were found to be directly proportional to increasing maturity indices.

Chemical composition

The chemical analysis of water chestnut peeled kernels was carried out and presented in Table 2. The moisture content in under matured kernel was 88.4% (wet basis), higher as compared to matured kernel (84.5%) and over matured kernel (76.2%). This is in accordance to Rodriguez *et al.* (1964). Due to considerable moisture content, it is believed to suppress stomach and heart burning on consumption at breakfast (Puste, 2004). Total ash content was found in the range of 0.52 to 0.70% with increase in maturity attributed to decrease in moisture content on maturity which is in lower range as compared to reported by Singh *et al.*, (2010) may be due to difference in variety and geophysical area. It is reported that water chestnut is a good source of mineral containing potassium (0.41%), iron (0.21%) and manganese (0.08%). The total protein in dried kernel powder was found to be 8.7% which is higher than reported by Singh *et al*. (2010). The difference could be attributed to variety and topography area of cultivation. The source of protein indicates good source amino acids which may give health benefit as reported by Kar *et al.* (2004).

The total sugar and reducing sugar was found to be decreasing from 4.9 to 3.8% and 3.6 to 2.4% with increase in maturity which could be attributed to increase in acid content on maturity and increase in starch content from 2.74 to 9.48%. Similar results were reported by Rodriguez *et al.* (1964). The alcohol insoluble solids were found to be 7.2%, 10.32% and 20.54% for under matured, matured and over matured water chestnut kernels.

Pre-treatment of Water chestnut slices

The water chestnut 150 g each sample were subjected to various pre-treatment with citric acid (1%, w/v) solution, blanching followed by 300 ppm KMS, fermented milk i.e. curd, churned diluted fermented milk i.e. buttermilk and salt solution (4%, w/v) for 8h and then samples were drained to remove excess moisture. 15 g samples were taken out to determine the moisture content of each sample before drying into cabinet tray dryer. The experimental data were fitted to polynomial equations (Table 3).

Effect of pretreatments on the drying characteristics of water chestnut

The data on experiment on moisture content present at any given time versus drying time were fitted to a first order polynomial model with a small modification as given by Krokida *et al.* (2000).

$$M_t = c_0 + c_1 t + c_2 t^2 \quad (1)$$

Drying characteristics of water chestnut have been shown in Figure 1. It is observed that the drying rate was faster in first 40 min as was the case in earlier studies reported by Walde *et al*. (2006). The initial moisture content of water chestnut pretreated samples by citric acid solution, salt, curd, buttermilk, blanched and control were 9.636, 5.367, 8.437, 5.536, 9.164 and 5.454% (db). The faster rate of removal of moisture was found to be in first 40 min in buttermilk treated sample and moisture content at the end of 40 min was recorded as 2.01% (db) followed by blanched (3.95%), curd (3.689%), salt (2.587%), control (2.915%) and citric acid (5.216%). The experimental data was correlated using Eq. (1) and regression coefficients were determined and found to be in the range of 0.9875-0.9947. It was evident from Figure1 that rate of evaporation was faster at higher moisture content at initial period of 40 min as compared to the moisture content falling from range of 4% (db) to 1% (db) particularly for the samples treated with blanching, curd and citric acid. After 150 min of drying time, the moisture loss was constant. The constant values evaluated by Eq. (1) are given in Table 3.

Drying rate curve

The drying rate curves of pretreated water chestnut were evaluated by differentiating equations with respect to time (Table 3).

$$v = -dM/dt$$

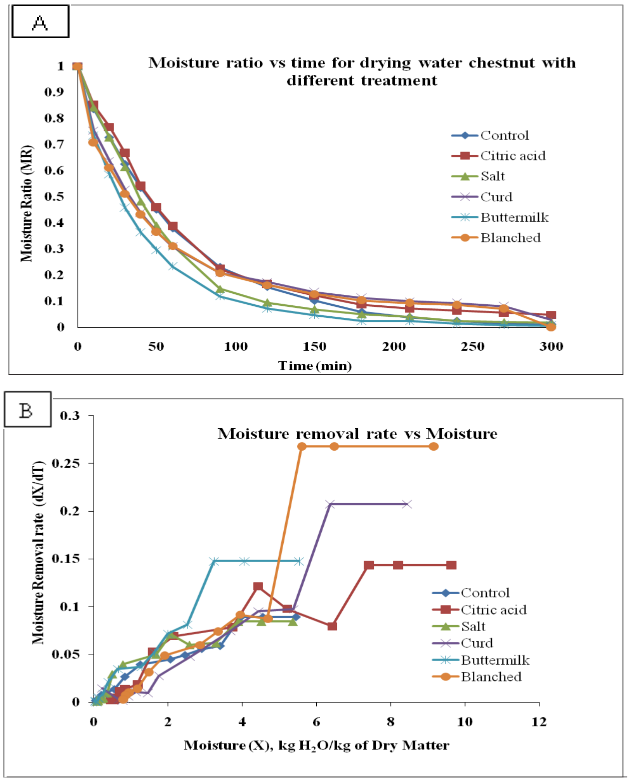

Figure 1. (A). Time vs. moisture ratio for drying of water chestnut with different treatment; (B). Moisture (X) vs. moisture removal rate (dX/dT)

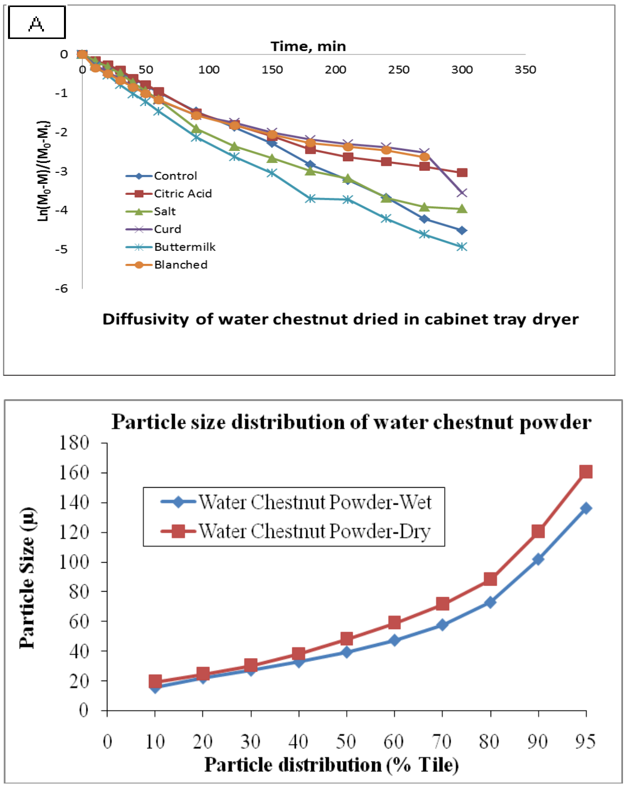

Figure 2. (A) Diffusivity of water chestnut dried in cabinet tray dryer; (B) Particle size distribution of water chestnut powder

Where M is the moisture content at any time *(t)* per unit weight of dry matter.

The drying rate curve (Figure 1A) for the water chestnut by cabinet tray drying have shown the linear falling rate except for the blanched, curd, citric acid treated sample. A single falling rate period with linear characteristic indicated that moisture diffusivity was by capillary forces at which stage the vapour pressure was more than partial pressure of moisture (Keey, 1972).

It was considered in the mathematical analysis that the moisture driving force during drying is liquid concentration gradient. The effect of heat transfer is neglected, since the heat transfer proceeds in a rapid manner during drying. In such situation, the convective drying of biological materials in the falling rate period is diffusion controlled process and may be represented by Fick's second law of diffusion. Similar results were reported by Singh *et al.* (2008) as drying of water chestnut slices took place with falling rate period. In Figure 1B, it has been indicated that moisture removal rate is higher at higher moisture concentration and lowered drying rate proportionately at falling rate period.

Diffusivity

The change in moisture concentration by diffusion can be represented by Fick's second law of diffusivity by the following Eq. (2).

$$dM/dt = Dd^2M/dx^2 \qquad (2)$$

As per Newman (1931), the above diffusion equation was available for three regular shapes viz., slab, cylinder and sphere in the form of concentration-time-locations. This can be used to predict the concentration at any given point throughout drying of water chestnut for ease of application. The following Eq. (3) can normalized the average moisture content.

$$\frac{M_0 - M_t}{M_0 - M_f} = \frac{\text{Final average free moisture content}}{\text{Initial uniform free moisture content}} \qquad (3)$$

Where M_f = final moisture content

Assuming that water chestnut slice is a slab of infinite extent, i.e. the radius is much greater than the thickness, and Newman's solution is

$$\frac{M_0 - M_t}{M_0 - M_f} = \frac{8}{\pi^2}\left[\exp\left(\frac{-1\pi^2}{4}\frac{Dt}{h^2}\right) + \frac{1}{9}\exp\left(\frac{-9\pi^2}{4}\frac{Dt}{h^2}\right) + \frac{1}{25}\exp\left(\frac{-25\pi^2}{4}\frac{Dt}{h^2}\right) + \dots\right]$$

$$= \frac{8}{\pi^2}\left[\sum_{n=1}^{\infty} \frac{1}{2n+1}\exp\left(\frac{-(2n+1)^2\pi^2}{4}\frac{Dt}{h^2}\right)\right] \qquad (4)$$

Neglecting the higher order terms in the above equation,

$$\frac{M_0 - M_t}{M_0 - M_f} = \frac{8}{\pi^2}\exp\left(\frac{-\pi^2}{4}\frac{Dt}{h^2}\right) \qquad (5)$$

Which on rearranging

$$-\ln\left(\frac{-\pi^2}{8}\frac{M_o-M_t}{M_o-M_f}\right)=\frac{\pi^2}{8}\frac{Dt}{h^2} \quad (6)$$

The first guess value of D was made by Eq. (6), by truncating the highest turn in Eq. (4). The exact value of D was calculated subsequently by trial and error by Eq. (4) by considering first 6 terms (Figure 2A) for water chestnut treating it as slab by taking the average half thickness (3.5 x 10^{-3}m). The diffusion coefficient (Table 3) was found maximum (1.353 x 10^{-9} m^2/s) for buttermilk treated water chestnut and minimum (0.719 x 10^{-9} m^2/s) for blanched water chestnut sample.

Effect of pre-treatments

The water chestnuts were treated with various pre-treatments before drying in cabinet tray dryer. However it was noticed that blanching, curd and citric acid treatments have lowered the rate of drying which could be attributed to absorption of moisture at blanching and hardening of starch molecular interspaces with curd protein and lactic acid which might have caused the hindrance in moisture diffusion and slower rate of evaporation in drying unlike mushroom (Walde *et al.*, 2006). The pretreatment of buttermilk on water chestnut has induced a small effect for faster evaporation of moisture and resulted in faster drying with diffusivity of (1.353 x 10^{-9} m^2/s) as compared to control (1.260 x10^{-9} m^2/s).

Particle size analysis

The powder made of dried water chestnut was analysed by particle size analyser in both state i.e., solid powder and dispersed in distilled water. It was found that the average particle size of water chestnut powder in dried state was of 65.82 micron (69%) and 39.54 micron in wet condition as suspension in water which is also shown in Figure 2B. The particle size in dried powder form was found more than that of water dispersed phase. This could be due to static force of dried particles which makes the powder particles to agglomerate with other particles present around them. However, in aqueous dispersed phase the static forces of particles gets weaker and separate from each other and hence particles size measured was of lesser as compared with the same in dry powder form.

Conclusion

The water chestnut were pretreated with viz., citric acid (1%, w/v solution); blanching followed by 300 ppm KMS; fermented milk i.e. curd; fermented whey i.e. buttermilk; and salt solution (4%, w/v) for 8 h and then samples were dried in cabinet tray dryer. The pretreatment of buttermilk on water chestnut has induced a small effect for faster evaporation of moisture and resulted in faster drying with higher diffusivity as compared to control. It was found that the average particle size of water chestnut powder in dried state was of more than in aqueous suspended condition.

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