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KINETICS OF DEHYDRATION OF AROIDS AND DEVELOPED DEHYDRATED AROIDS PRODUCTS

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Abstract
The study was concerned with the dehydration kinetics of aroids in mechanical dryer at different drying condition such as variable air dry bulb temperature and air velocity. Fresh aroids with 3, 5 mm slice and 8 mm cube were used as raw materials for drying. The experimental results showed that drying rate constant and thickness can be expressed as power law equation. The exponent of the equation for aroids was 1.15 indicating presence of significance external mass transfer resistance. Increasing loading density gave decreased drying rate constant and when air velocity of dryer was increased, drying rate constant was also increased, as higher air velocity reduces the external resistance to mass transfer and also higher temperature gave faster drying rate. The activation energy of diffusion of water from aroids during drying as per Arrhenius equation was found to be 5.12 k cal/g-mole. The chemical compositions of fresh and dried aroids were determined and it was observed that all the constituent remained almost constant, only fat decreased slightly possibly due to oxidation. Organoleptic taste testing showed that "chapatti" prepared from aroids powder (aroids powder: wheat flour = 1:4) were adjudged to be the best by the panelists using 1-9 hedonic scale and ranked as like moderately securing score 7.3.

Introduction

Aroids (*Colocasia esculenta*) locally known as "kachu" is a tropical tuber crop cultivated in Bangladesh for its leaves, corms and cormels. Different types and sizes of aroids are grown in Bangladesh and mainly cultivated in greater Mymensingh. From the economic point of view, the aroids are important root crops for most of the tropical developing and some of the developed countries. Flour made from aroids is an excellent starchy food and was prescribed to cereal allergy sufferers[8]. Chowdhury[5] reported that the nutritive value of corms of aroids seems to be comparable with that of the other starchy foods. Notwithstanding their high starch content, edible aroids have a higher content of protein and amino acids than many other tropical root crops[14]. Protein quality is essentially the same for all aroids determined with lysine as first limiting amino acid[4].

A comparative chemical analysis per 100 g of rice, potato and corms of two of the aroids indicates that besides being comparable in respect of some nutrient contents, the corms seem to be richer in Ca and Fe[16]. Flour made from aroids is an excellent starchy food and is highly digestible due to small grain size[6]. According to Gerpacio *et al.*[7] the advantage of using aroids for preparing infant food is that it contains an appreciable amount of protein and it does not contain hydrocyanic acid or any toxic substance in amount which is generally found in case of cassava. Its higher digestibility is an added advantage for its suitability for this purpose. Converting tubers into flours and starches may be an important process that could contribute to minimizing losses and to allow the commercial food industry to store the tuber throughout the year by using appropriate drying technology. Preservation by drying of this vegetable can prevent the wastage and make them available in the off-season. Processing of this vegetable into shelf-stable products using efficient drying procedure and effective utilization of the finished products will enhance availability of the vegetable throughout the year. Moreover, this will stimulate increased production, bring better returns to the farmers and improve nutritional status of the people. Drying can be accomplished in a mechanical dryer, direct sunlight or solar dryer. In the mechanical dryer, desired temperature and airflow could be maintained. Compared to sun/solar drying higher airflow and temperature can be used in mechanical drying. As a result higher production rates and improved quality products are achieved. Moreover mechanical drying is being independent of sunlight it can be done as and when necessary.

So the objective of this work was to study the dehydration kinetics of aroids using mechanical dryer and develop aroids flour that could be used as a supplementary raw material for the production of "chapatti" and to assess the overall acceptability of the developed products.

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Materials and methods

Fresh aroids grown in Mymensingh were used for drying process to develop dried aroids slices and aroids powder. Aroids were sliced into desired thickness and placed in trays as to form a single layer and drying commenced in dryer. Weight loss was used as a measure of extent of drying. Initial moisture content was determined as per method of Ranganna[17]. AOAC[2] methods were used to determine crude fat and protein content of the aroids.

Experimental Apparatus

Forced convection hot air type cabinet dryer (Figure 1) was used for drying of aroids.

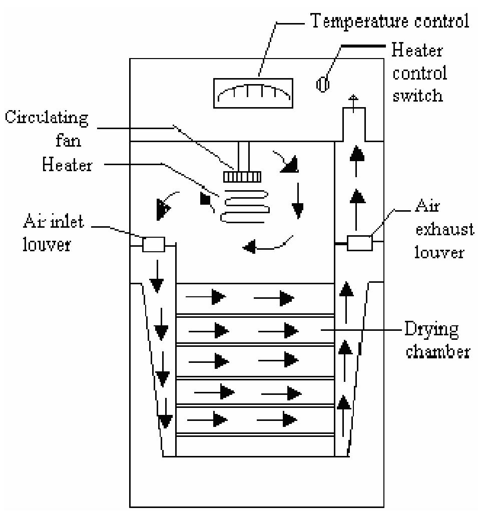

Fig 1. Schematic diagram of forced convection hot air type cabinet dryer

The dryer consisted of an insulated cabinet containing a circulating fan, which was fixed over the heating element (heater) and above the cabinet chamber. When the equipment was run, the circulating fan drew air through the heater and this heated air was forced to the chamber through the adjustable louvers at the inlet port. This heated air then passed into the chamber and over the product which was placed on trays. The heated air, having less moisture content, picked up moisture from the exposed food materials placed on the trays and having a higher moisture content. The moist air then left the chamber and went out through exhaust port. The exhaust air was controlled by an adjustable louver at the outlet port. The velocity of air was measured (0.6 and 1.25 m/sec.) by an Anemometer.

Characteristics dimensions of dryer:

Size =2mx1mx0.84m

Chamber size =1mx0.64mx0.66m

Temperature range = 38^0C to 340^0C

Analysis of experimental data

Since food dehydration is most frequently assumed to take place by diffusion process, Fick's second law of diffusion can be applied for describing mass transfer during drying. The expression is

$$\frac{\delta M}{\delta t} = \nabla^2 D_e M$$

Where, M = Moisture content

T = Time

D_e = Effective diffusion co-efficient

The solution of the above unsteady state diffusion equation for one dimensional transport for the case of initial uniform moisture distribution in the sample was derived by Brooker et.al[3] and Islam[12] when dried from one major face is:

$$\text{MR}= \frac{M_t - M_e}{M_o - M_e} = \frac{8}{-} = \frac{8}{\pi^2} \sum_{n=0}^{\alpha} \frac{1}{(2n+1)^2} \text{Exp} \left[\frac{-(2n+1)^2 \pi^2 D_e t}{L^2} \right] \text{------ (1)}$$

For low M_e values and for moisture ratio (MR) less than six, equation (1) reduces to,

$$\frac{M_t}{M_o} = \frac{8}{\pi^2} \; e^{-\pi^2 Det / L^2} = \frac{8}{\pi^2} \; e^{-mt} \text{------ (2)}$$

Where,

M_t = Moisture content at any time

M_0= Initial moisture content

M_e = Equilibrium moisture content

L = Sample thickness

T = Time

$$m = \frac{\pi^2 D_e}{L^2} = \text{drying rate constant, sec}^{-1}$$

Consequently, a straight line should be obtained when plotting lnMR versus time (t). The slope of the regression line is the drying rate constant, m from which the effective diffusion co-efficient, D_e is calculated.

The diffusion co-efficient, D_e has an Arrhenius type of relationship with air-dry bulb temperature (abs). The relationship is as follows[9]:

$$\ln D_e = \ln D_o - \frac{E_a}{RT_{abs}} \text{----------(3)}$$

Where, D_0 = the constant of integration and is usually referred to as a frequency factor when discussing Arrhenius equation; E_a = activation energy of diffusion of water, cal/g-mole;R=gas constant, cal/g-mole°K; and T_{abs} = absolute temperature, °K.

From the semi-theoretical equation as shown in equation (2), symbolically 'm' may represented as: $m = A(L)^{-n}$
or, $\log m = \log A - n \log L$ ------(4)
Where, $A = \pi^2 D_e$ and $n = 2$
The above relationship shows that if external resistance to mass transfer is negligible and if simultaneous heat and mass transfer effects are taken into account, the value of the exponent of the power law equation should be 2. But the above conditions are not always satisfied and experimentally determined 'n' value is found to be less than 2 as reported by co-author[12].

Results and discussions

Experiment was conducted to determine the effects of loading density (mass/unit area) as well as thickness of aroids on drying rate at three different temperatures (55°C, 60°C and 65°C) in a cabinet type of mechanical dryer. Experiment was also conducted to investigate the effect of air velocity on drying rate at constant temperature.

Effect of loading density on drying time

To determine the influence of loading density on drying time, 1.2 kg/ m^2 and 2.4 kg/ m^2 aroids slices were dried at different dry bulb temperature (55°C, 60°C and 65°C) at constant air velocity in a cabinet dryer. The drying rate constants were calculated by a regression analysis for each sample thickness using equation (2) and moisture ratio (MR) versus drying time (hr) were plotted on a semi-log scale (Fig.2) and rectangular scale (Fig.3).

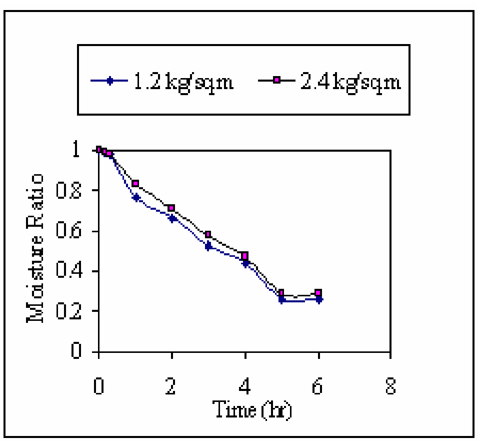

Fig 2. Effect of loading density on drying rate at 55°C.

The following regression equations were developed:
$MR = 1.0289e^{-0.2384t}$ for 1.2 kg/m^2
$MR = 1.049e^{-0.223t}$ for 2.4 kg/m^2

From Fig 2 and 3 it is seen that as loading density of aroids increases the rate of drying decreases, but drying rate constant does not decreases proportionately as loading density increases. Using 1.2 kg/m^2 loading density, the rate constant was 0.238 hr^{-1} at 55^0C, whereas for twice the loading density at similar condition the rate constant was 0.223 hr^{-1}. This phenomenon can be advantageously used for increased dryer thoroughput. However, care should be taken not to increase loading density to such an extent that may increase drying time to a level at which the products are spoiled.

Influence of thickness on drying rate

To investigate the effect of thickness on drying behavior aroids slices were dried at constant air dry bulb temperature (60^0C) and constant air velocity (0.6 m/s). The results were analyzed by using equation (2) and are shown in Table-1. The equations developed are as follows:

$MR = 1.0026e^{-0.3987t}$ for 2 mm slice
$MR = 1.0397e^{-0.2567t}$ for 3 mm slice
$MR = 1.0842e^{-0.1521t}$ for 5mm slice

By putting MR value = 0.13 in the above equations, it is seen that for removal of 87% moisture 2mm aroids slice takes only 5 hours whereas 3 and 5mm aroids slices needed 8 and 14 hours respectively. So the products can be made shelf stable within these time.

From Fig. 3 and Table 1 it is also clear that thickness of the sample directly influences total drying time.

Table 1: Thickness dependence of drying rate constant of aroid slices

Thicknes (cm)	Drying rate constant (sec^{-1})
0.2	1.10×10^{-4}
0.3	7.13×10^{-5}
0.5	4.22×10^{-5}

The relationship between drying rate constant (m) and sample thickness (L) was developed (Fig. 4) from the plot of drying rate constant versus sample thickness on log-log scale using equation (4). This relationship can be represented by a power law (regression) equation, which is as follows.
$m = 0.9445L^{-1.1451}$

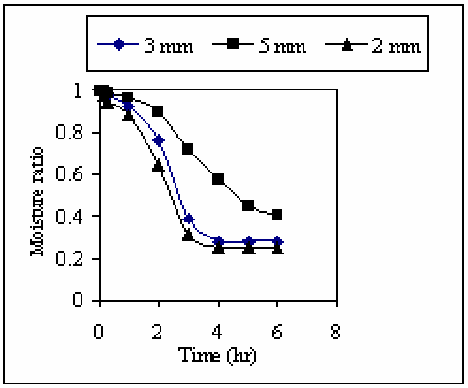

Fig 3. Effect of thickness on drying behavior of aroid slices at 60°C.

From the above equation, it is seen that the value of index 'n' of the power law equations is 1.14 at 60^0C. This value is lower than 2 as predicated by equation (4) and it indicates that the external resistance to mass transfer is highly significant under the given conditions. This also indicates that higher airflow rates will give higher drying rates. Islam[12] showed an 'n' value of 1.70 while drying potato using higher airflow rates (2.5 m/s). The above discrepancy of 'n' values is primarily due to airflow rate and sample thickness, and shows the relative importance of external or internal mass transfer resistance. However, product structure and composition and simultaneous heat and mass transfer effects also play an important role in this regard. Islam[12] while working with potato, showed that by taking into account of the simultaneous heat and mass transfer effect value of 'n' could be corrected to 2 from 1.7.

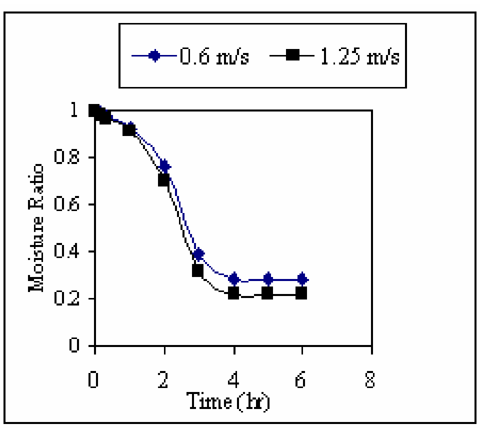

Fig 4. Influence of air velocity on drying rate at 60°C for 3 mm slice.

Influence of air velocity on drying time

From Fig. 5 and 6 it is obvious that when air velocity is increased, drying rate constant is also increased, as higher air velocity reduces the external resistance to mass transfer. The decrease in external resistance leads drying to be controlled by increasing internal resistance to mass transfer as is important for analyzing drying data according to Fick's diffusion equation. However, doubling the air velocity did not increase the rate constant twice as much. Moreover, for certain drying conditions, there may be a fixed air velocity above which increase in velocity will not result in increased drying rate[12].

Influence of temperature on drying time

From Fig 7 it is seen that the moisture ratio (MR) decreases with time and time to dry to a specific moisture ratio decreases with increasing temperature. Thus higher temperature would give faster drying rate. At very high temperature and low humidity drying rate may initially increase, but as drying progresses resultant case hardening would reduce drying rate drastically and deteriorate the quality of the product due to cooking instead of drying. High temperature also may scorch the product and thus selection of optimum temperature for drying is of significance during drying particularly, mechanical drying with counter current operation[13,15].

From the drying rate constants determined by regression analysis, the diffusion co-efficients were determined. Diffusion co-efficient (D_e) versus inverse absolute temperature (T_{abs}^{-1}) was plotted on a semi-log co-ordinate and regression lines were drawn. From the slope of the resultant straight line (Fig. 8), activation energy (E_a) for diffusion of water was calculated and found to be 5.12 Kcal/g-mole.
The calculated activation energy is lower than 12.5 Kcal/g-mole of activation energy for diffusion of water from potato by Saravacos and Charm [18], those found by Afzal Babu *et al.*[1] for onion (26.83 Kcal/g-mole) and for cucumber (8.50 Kcal/g-mole), and cauliflower (7.76 Kcal/g-mole) found by Iqbal[10] but higher than that found for mango (4.4 Kcal/g-mole) by Islam *et al.*[11] .That means the activation energy value is within the range of values reported by many researcher. The differences in activation energy may arise from differences in product characteristics as well as process parameters.

The dependence of diffusion coefficient on absolute temperature can be represented as

$D_e = 0.0015\, e^{-2574.3}\, T_{abs}^{-1}$
Where,
D_e = Diffusion coefficient (cm^2/s) and
T_{abs} = Absolute temperature (°K)

Table 2: Influence of temperature on diffusion coefficient

Temperature (^{O}C)	Diffusion coefficient (cm^2/s)
55	$4.43x10^{-7}$
60	$6.50x10^{-7}$
65	$1.07x10^{-6}$

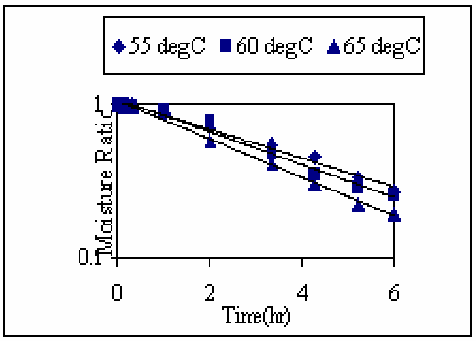

Fig.5: Effect of temperature on drying rate at constant loading density (1.2 kg/m^3)

Comparison of composition of fresh and dried aroids

The fresh aroids contained 91.2% moisture, 0.38% protein, 0.22% fat, 1.24% ash and 6.96% carbohydrate where as the mechanical dried aroids contained 11.4% moisture, 2.52% protein, 0.09% fat, 7.86% ash and 78.13% carbohydrate (Table 3). During drying most of the water in the aroids are vaporized so the moisture content is so less and consequently solid content increased. This increased solid content results in the increased protein, ash, and carbohydrate content. The fat content decreased in the dried sample, which may be due to the oxidation of fat during drying.

Table 3: Comparison of composition of fresh and dried aroids

Parameters	Fresh aroids (%)	Dried aroids (%)
Moisture	91.2	11.4
Protein	0.38	2.52
Fat	0.22	0.09
Ash	1.24	7.86
Total carbohydrate	6.96	78.13

Development of product

The dried aroids were grinded in a laboratory grinder and aroids powder was obtained. Then “chapatti” was prepared by mixing wheat flour and aroids powder at different ratio. The products are then tested organoleptically.

Sensory evaluation of developed product

The consumer's acceptability of developed products was evaluated by a taste testing panel. The 1-9 hedonic rating test was used to determine this acceptability. A two way analysis of variance (ANOVA) was carried for color, flavour, texture and overall acceptability preference of developed product and the results are shown in Table 2.

As shown in Table 2 (DMRT) the sample 1 was the most acceptable product securing the highest score 7.3 (out of 9) among the samples and ranked as “like moderately”. However, sample 2 and 3 were equally acceptable at 5% level of statistical significance securing score 6.2 and 5.5 respectively and ranked as “like slightly”. But sample 4 secured the lowest score (4.8) and was ranked as “neither like nor dislike”.

Table 2. Mean score for color, flavor, texture and overall acceptability of “chapatti”

Sam-ple	Sensory attributes			
	Color	Flavor	Texture	Overall Acceptability
1	7.0^a	6.3^b	7.1^a	7.3^a
2	6.1^b	7.6^a	5.8^b	6.2^b
3	5.6^{bc}	5.3^c	5.1^b	5.5^{bc}
4	5.1^c	4.4^d	4.3^c	4.8^c

Sample 1: Aroids powder: wheat flour = 1:4
Sample 2: Aroids powder: wheat flour = 1:3
Sample 3: Aroids powder: wheat flour = 1:2
Sample 4: Aroids powder: wheat flour = 1:1

Conclusions

This study demonstrated that the aroids flour could be conveniently incorporated into wheat flour for the production of “chapatti” in order to produce “chapatti” of acceptable quality. Hedonic rating test for organoleptic quality indicated that 20% of aroids flour could be added in the production of “chapatti” to maintain acceptable scores for color, flavour and texture of the product. Every year a substantial amount of aroids are cultivated in Bangladesh. The study showed that there is a good prospect of processing of aroids through diversified and value-added products. By processing aroids its market value may be increased and production can be maximized. Therefore, it may be concluded that, aroids can be successfully and economically preserved during its peak season by drying process.

Mechanical drying systems may be used for large-scale production.

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