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Rehydration Characteristics and Structural Changes of Sweet Potato Cubes after Dehydration

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ABSTRACT

Moisture removal from solids is an integral part of food processing with convective drying representing one of the most important techniques for preservation of biological products. However, removal of moisture during drying has detrimental effects on the physiochemical properties of the material. For evaluating of the rehydration capability the sweet potato cubes of 1.2×1.2×1.2 cm were dried to final moisture content of 6-7% (d.b.) under air temperature of 50, 60, 70, 80 and 90°C and air velocity of 3.5 m sec^{-1} in a laboratory scale hot air dryer. Deterioration of the physical attributes of the system was evaluated on the basis of rehydration characteristics, namely the coefficient of rehydration and rehydration ratio at different soaking time period of 10, 15, 20, 25 and 30 min. Structural changes in Sweet potato cubes after drying were studied by light microscopy. The rate and degree of dehydration was dependent on the drying conditions, with extent of cellular and structure disruption dictating the rehydrational capacity. The drying temperature had an effect on the shrinkage of cell structures of sweet potato. It was observed that the degree of shrinkage of sweet potato during low temperature drying is greater than at high-temperature during drying.

Key words: Dehydration, coefficient of rehydration, rehydration ratio, microstructure, sweet potato

INTRODUCTION

During any drying operation, one critical entity, competing with that of process economics is quality preservation. Although most dehydrated fruits and vegetables are produced by hot air dehydration. In general, conventionally air dried products tend to exhibit indifferent quality attributes due to excessive thermal damage and further present reduced reconstitution attributes, due to the structural disruption incurred during drying, e.g., shrinkage and internal porosity (Sandhu and Parhawk, 2002; Pimpaporn *et al.*, 2007; Prachayawarakorn *et al.*, 2008). The use of high temperature in food processing is commonly known to cause detrimental changes to the processed products (Yang and Gadi, 2008). Drying temperature affects the sensory attributes and flavor of pistachio nuts during high temperatures drying (116-138°C) as reported by Kouchakzadeh and Tavakoli (2010). Many aspects of the rehydration phenomena have been addressed throughout the literature. However, this research was restricted to evaluating system rehydratability as a criterion of structural quality (Prakash *et al*., 2004; Taiwo and Baik, 2007; Singh *et al*., 2006; Jayaraman *et al*., 1990). And microstructural changes in Sweet potato after drying using light microscopocity as reported by Wang and Brennan (1995) in dehydrated potato slices. Kerdpiboon *et al*. (2007) reported significant physical changes in term of percentage of shrinkage and rehydration ratio of carrots and potato samples after undergoing conventional hot air drying. These apparent changes correlated well with their microstructural changes represented by the normalized changes of fractal dimension of microstructural images.

Degree of rehydration is dependent on processing conditions, sample preparation, sample composition and extent of the structural and chemical disruption induced by drying (Singh *et al*., 2006). Investigation correlating the duration and severity of the drying process with the speed and degree of rehydration indicate faster and more complete rehydration with decreased drying time. This reflects a minimization of shrinkage and therefore, the presence of well-defined intercellular voids to promote increased rehydrating rate (Cano-Chauca *et al*., 2005; Haas *et al*., 1974). The rate of rehydration of the plantain and banana samples was found to decrease with increasing dehydration and rehydration time as reported by Agunbiade *et al*. (2006).

Jayaraman *et al*. (1990) examined the tissue structure of air-dried cauliflower. The sample were reported to exhibit irreversible cellular rupture and dislocation, resulting in loss of integrity and hence a dense structure of collapsed and greatly shrunken capillaries. Accordingly, this rendered reduced hydrophilic properties, as reflected by the inability to imbibe sufficient water to dehydrate fully. The physiochemical basis for the structural deformation was the loss of selective semi-permeability of the cytoplasm membranes and the resultant loss of turgor pressure in the cell. Moreover, in the work of Mayor and Sereno (2004) and Neuman (1972) further causative factors for limited water uptake were suggested, namely starch crystallinity, protein denaturation and hydrogen bonding of the macromolecules.

Different drying methods affect the compactness of the tissue structure. The fibers become more disrupted resulting in coherent structure with hardly any spaces between the fibres (Dewi *et al*., 2011). Askari *et al*. (2004) used interference microscopy to determine changes in refractive index and volume of cellulosic plant cell walls with varying moisture contents. Cano-Chauca *et al*. (2005) and Prachayawarakorn *et al*. (2008) studied on the application of microscopic techniques for analyzing the structure of dehydrated food materials and of the relationship between the observed structure and some physical properties of the foods.

Therefore, in view of the limited data pertaining to rehydrational characteristic and structural changes in dried product, this study was carried out to investigate the effect of drying temperature on rehydration quality and microstructual changes of sweet potato.

MATERIALS AND METHODS

Experimental material: Sweet potato (*Ipomoea batatas* L.) used for the drying experiments were purchased from local market, Pantnagar, Uttarakhand (India). The sweet potato was diced uniformly into cubes of 1.2×1.2×1.2 cm and was dried on the same day. The initial moisture content of sweet potato was 541.85% (d.b.) and was estimated by Association of Official Analytical Chemist AOAC (1990) method. The experiments were conducted during the months of February-April, 2010 in the Department of Post Harvest Process and Food Engineering, College of Technology, G.B Pant University of Agriculture and Technology, Pantnagar, Uttarakhand-263 145 (India).

Experimental setup: The drying experiments were performed in the experimental cabinet hot air dryer, consisting principally of a fan, heating section and drying chamber. The experimental system was operated at ambient moisture conditions, i.e., average room air conditions were 23±2°C and 50±3% relative humidity. On setting the dryer to the desired conditions of air velocity-controlled outlet centrifugal fan and air temperature-regulated by a PID temperature controller, the system was allowed to stabilize for approximately 1 h to ensure equilibrium conditions. The prepared sample was dried by radial diffusion and was positioned directly on the drying tray which was located within the drying chamber. Moisture loss was recorded in 5 min intervals during the first 40 min and later on 10 min intervals by a digital balance of ±0.001 g accuracy (Mettler, Germany). The drying was continued until there was no large variation in the moisture loss. Experiments were replicated three times and corresponding quality measurements were averaged.

For evaluating of the rehydration capability the sweet potato cubes (initial 1.2×.2×1.2 cm) were dried to a final moisture content of 0.6-0.7 kg kg^{-1} dry solid under air temperature of 50, 60, 70, 80 and 90°C and air velocity of 3.5 m sec^{-1}.

The rehydration tests were conducted as recommended by USDA (Anonymous, 1944). The experimental reconstitution data were correlated with time of rehydration according to a second order polynomial relation to describe the mathematical description of rehydration phenomenon:

$$RR = at^2 + bt + c \tag{1}$$

where, RR is the rehydration ratio; t is the rehydration time (min) and a, b and c are the coefficients.

Microstructural changes in sweet potato after drying were studied using light microscopy (Yam *et al.*, 2004; Papadakis *et al.,* 2000; Boutelje, 1972). The paraffin method was studied. The procedures involved in this method of microtoming are: fixing, washing, dehydration, infiltration, embedding, microtoming, mounting, staining, dehydration and mounting. For sectioning, micro-films were prepared 1 mm below the surface of sweet potato and later on mounted on slides. Photomicrographs of parenchyma cells in Sweet potato in the horizontal sections were taken with help of Dig Pro 4.0 compound microscope at 10x magnification.

RESULTS AND DISCUSSION

Removal of water from a cellular structure induced variations in the physical attributes of the system. The rehydration characteristics of sweet potato samples dried at different air temperatures are illustrated in Fig.1. Figure 1 showed that there was a significant rehydration in cubes of sweet potato in distilled water. This may be due to the high content of starch. Similar behavior of significant rehydration by soaking dehydrated chips of banana in boiling water resulting in increased rehydration rates was reported by Agunbiade *et al.* (2006). Rehydration is a complex process and indicates the physical and chemical changes caused by drying and treatments preceding dehydration (Lewicki, 1998; Feng and Tang, 1998). It was also observed from the Fig.1 that the rehydration ratio of sweet potato cubes dried at lower temperature was lesser as compared to the higher temperature. The lower rehydration values are evidence for product shrinkage caused by prolonged drying resulting in irreversible physic-chemical changes. Funebo and Ohlsson (1998) reported similar trend in microwave assisted air drying of apple and mushroom.

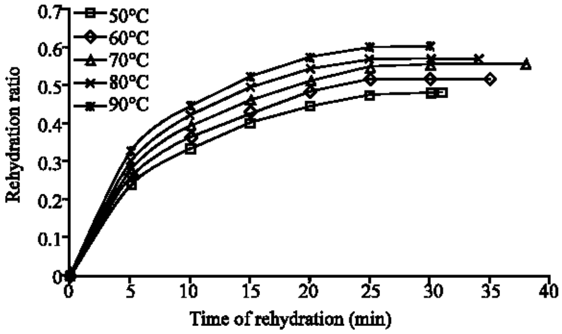

Fig. 1: Influence of drying air temperature on rehydration capacity

Sandhu and Parhawk (2002) also reported the slow dehydration at low temperature resulting in hard dense product and more porous materials at higher drying temperature, which rehydrated more rapidly. However, Nimmol *et al.* (2007) observed dissimilar trend in the case of vacuum-FIR drying of banana slices at lower temperatures (60 and 70°C) which yielded the dried products with lower degrees of shrinkage and consequently resulted in more rehydration ratio. Devahastin *et al.* (2004) also observed that despite the longer drying time in the operating ranges tested, carrot dried by LPSSD had superior quality in term of rehydration behavior, which was contradictory in case of sweet potato drying. Sunjka *et al.* (2008) reported that longer drying time/longer power off time in MW/vacuum drying was beneficial for water redistribution inside the fruit, giving more uniformity dried product with better rehydration properties which contradicted with the present observation in sweet potato cubes. On placing the dried sample into water, the cell walls absorbed water, softened and then due to the natural elasticity of the cellular structure, the cells returned to their original shape by drawing water into the inner cavities (Gane and Wager, 1958). The volume of absorbed water increased with increasing rehydration time, irrespective of the air drying temperature. This was manifested in a relatively rapid rate of reconstitution during the early stages, followed by a more gradual increase in rate, tending towards a maximal rehydration ratio. This rapid moisture uptake was due to surface and capillary suction. In general, temperature strongly increased in the early stages of water rehydration.

Table 1 presented the results of the regression analysis. The effects of temperature on the rehydration were appreciable within the range of conditions studied. The non-linear polynomial expression for all temperature ranges were fitted and showed significantly correlated as their coefficient of determinations (R^2) were greater than 0.990. The range of application of rehydration time for the temperature ranges also indicated that there was no significant gain in the moisture content of rehydrated product beyond the range (0-31 min) at 50°C. The rehydration ratio (RR) ranged from 2.831 to 4.502 in the entire temperature range under study.

Microstructures of the dried samples under different drying conditions are presented in Fig. 2a-f. It can be seen in Fig. 2a that in structure of fresh (control) sweet potato, the cell walls were quite intact. The lumps of starch granules were surrounded by a thin cell membrane. The particles showed a high degree of uniformity with strong adherence among the particles, verifying a set of scattered particles. Similar finding was reported by Cano-Chauca *et al.* (2005) in mango drying. After drying morphologies of sweet potato cubes were noticeably different from that of the reference sample; the dried samples became porous whilst the morphology of the reference sample

Table 1: Rehydration characteristics of sweet potato samples dried at different air temperatures

Temperature (°C)	Rehydration relation	R^2	Range of application (min)	Rr_{max}
50	$RR = -0.002t^2+0.123t+0.940$	0.995	$0 \le t \le 31$	2.831
60	$RR = -0.002t^2+0.141t+0.963$	0.997	$0 \le t \le 35$	3.448
70	$RR = -0.002t^2+0.153t+0.984$	0.998	$0 \le t \le 38$	3.910
80	$RR = -0.003t^2+0.204t+1.034$	0.998	$0 \le t \le 34$	4.502
90	$RR = -0.003t^2+0.178t+0.998$	0.998	$0 \le t \le 30$	3.634

Range of application indicates the range of rehydration time (min) beyond which there is no gain of moisture during rehydration

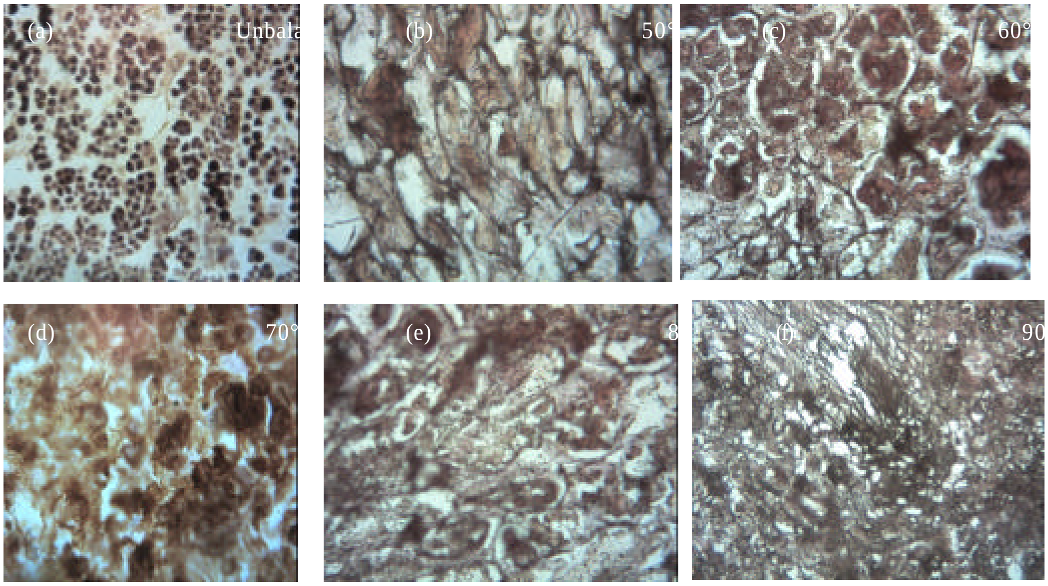

Fig. 2(a-f): Photomicrograph of parenchyma cells in sweet potato cubes in horizontal sections dried at different temperatures (50-90°C) at 3.5 m sec^{-1} air velocity

was relatively dense. Figure 2b presented the structural changes in sweet potato in the horizontal section after drying at 50°C. Drying at low temperature took more time and the cells became elongated and later on lead to twisting of the cells and clumping of the cytoplasm. The pore formation after drying is possibly due to the evolution of the water vapor inside the samples. The pores development depended strongly on the drying temperature used. The highly porous banana slices were obtained when using the temperature higher than 120°C and became less porous at lower drying temperature (Prachayawarakorn *et al*., 2008). Longer drying time at lower temperature resulting in lesser rehydration ratio was also reported in HTST drying of sweet potato slices by Antonio *et al*. (2008). Sweet potatoes exposed to heat treatment served to maintain a low degree of pectin methylation which formed calcium bridges between the free carboxyl groups of adjacent molecules, thereby resulting in a firmer texture (Abe *et al*., 2011).

During blanching before drying the thin cell membrane ruptured and starches granules started partial gelatinization. With increase in blanching temperature of distilled water and prolonged hot air drying, greater degree of gelatinization of starch occurred due to degradation of starch by amylases which resulted in decreased water binding capacity during rehydration as reported by Yadav *et al*. (2006). It was observed that shrinkage occurred first at the surface and then gradually moved to the bottom with increase in drying time (McMinn and Magee, 1995). The cells became elongated when dried at higher temperature from 60-90°C as could be seen in Fig. 2c-f. The shrinkage of sweet potato cubes depended on the drying temperature. A lesser extent of shrinkage was found at higher drying temperatures. The lower shrinkage of sweet potato at higher drying temperatures can be attributed to the lower moisture content of the external surfaces, which might induce a rubbery-glass transition and the resulting formation of rigid crust at the outer layer that helped fixing the size of samples (Mayor and Sereno, 2004). At higher temperature the evaporation of moisture from the surface was faster hence the outer layer of the materials became rigid and the final volume was fixed early period in the drying. As drying proceeded, the tissues split and ruptured internally forming an open structure. On further drying the interior finally dried and shrunk, the internal stresses pulled the tissue apart. The dry material then contained numerous holes. This agrees with the finding of Van Arsdel *et al.* (1973).

CONCLUSION

The reconstitution attributes are indicative of the degree of structural modification incurred during drying. The rehydration characteristic correlated positively with the air drying temperature. It was observed through microscopy that the degree of shrinkage of sweet potato by low temperature drying was greater than by high-temperature drying. Shrinkage affected the physical properties of materials, such as the rehydration characteristics and coefficient of rehydration.

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