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Science and Technology

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Journal of Food, Agriculture & Environment Vol.11 (1): 259-263. 2013

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Batch drying characteristics of dent corn (*Zea mays* var. *indentata* Sturt.)

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Received 28 October 2012, accepted 20 January 2013.

Abstract

The batch drying characteristics of dent corn were investigated in a batch-type laboratory hot-air dyer over a temperature range of 30-60°C. The results showed that increasing the drying air temperature caused shorter drying times and all of the sample drying occurred in the falling-rate period, with the exception of a very small amount that occurred in the heating-up period. Additionally, the colour and structural changes of fresh and dried corn kernels were investigated. Among all of the drying conditions, the closest values to the colour of fresh corn were obtained at 30°C. Scanning electron microscope images revealed that the low drying temperatures of 30°C and 40°C did not cause clear differences in the granular integrity of the products' starch structures compared with fresh samples. However, the high temperatures of 50°C and 60°C during the drying process caused a more violent evaporation of water and the melting of the starch granules.

Key words: Batch drying, dent corn, colour, microstructure.

Introduction

Corn is one of the most important cereal grains in the world [1, 2]. The production of corn has great economic importance due to the large quantities of starch, corn syrup, ethanol, oil, chemicals and other products that are produced from this crop [3]. Additionally, corn is consumed worldwide as a food ingredient and animal feed[4]. There are various types of corn in the world [5]. Varieties of dent corn (such as *Zea mays* var. *indentata* Sturt.) contain both hard and soft starches, and the kernels become indented at maturity, with a depressed crown [6, 7]. Corn kernels have a high initial moisture content at harvest and must be dried to achieve a safe moisture level for long-term storage [3, 8].

Drying is one of the most important unit operations in food processing and represents a feasible way of extending the shelf life of foods with high moisture contents, especially fruits and vegetables, by reducing their water content to a level at which microbial spoilage and undesirable reactions are minimised [9-11]. Drying also brings about substantial reductions in the weight and volume of foods, thereby minimising the packaging, storage and transportation costs [12-14].

The most common method used for drying is hot-air drying, due to the low investment and operation costs and the ease of operation [15-17]. This technique is most suitable for solid materials, such as grains, sliced fruits and vegetables, and chunked products[18]. Several factors can inuence the hot-air drying of food, including the velocity and temperature of the air, water diffusion through the material, and the load density, thickness and shape of the product to be dried [19]. Therefore, the drying conditions must be optimised to obtain high-quality dried products [10, 18, 20]. The study of the drying kinetics of foods during hot-air drying has recently been a subject of interest to various investigators. The foods investigated include carrot [17], tomato [21], wheat [22], soybean[23], red pepper [24], apple [25], mushroom [26], plum [27], eggplant [28], potato[29] and corn [30].

The objectives of this study were to examine the effect of temperature on the drying behaviour of corn and to investigate the colour and microstructural differences between the fresh and dried products.

Materials and Methods

Drying equipment and drying procedure: The dent corn seeds used in the study were obtained from the fields of the Agricultural Faculty of Uludag University, Bursa, Turkey and stored at a temperature of 4 ± 0.5°C until the drying process [31]. The seeds were cleaned manually to remove all foreign matter, such as dust, dirt, stones and chaff, as well as immature or broken seeds [32]. The initial moisture content of the seeds was determined by oven drying at 105 ± 1°C for 24 h [33].

The drying of the corn was conducted in a batch-type laboratory hot-air dryer that could be set to any desired drying air temperature between 20 and 100°C. The dryer basically consisted of a drying unit (a cylindrical chamber) with an inner diameter of 30 cm, a height of 100 cm, a centrifugal fan to supply the air flow, an electric heater, an air filter, and an electronic proportional controller. The air temperature was regulated by the proportional controller. The air flow rate for all of the drying runs was 1 m s^{-1} and was measured by a digital anemometer (Thies Clima, Germany) with a sensitivity of 0.1 m s^{-1}; the flow was perpendicular to the drying bed. The air was recirculated by a variable-speed fan and heated by electricity.

The change of the mass of the sample was detected continuously using a load cell (Esit, S type, Model STCS, Turkey) connected to a USB datalogger (Model USB-V1.0, Turkey) and a personal computer to record the data at 15-min intervals during the drying process [29, 34]. This strategy provides a very fast and precise method for determining the product moisture content on-line [35].

The moisture ratio (MR) and the drying rate of corn samples during the drying experiments were calculated using the following equations [36-38]:

$$MR = \frac{M_t - M_e}{M_o - M_e} \quad (1)$$

$$\text{Drying rate} = \frac{M_{t+dt} - M_t}{dt} \quad (2)$$

where M_t is the moisture content at a specific time (kg water/kg dry matter), M_o is the initial moisture content (kg water/kg dry matter), M_e is the equilibrium moisture content (kg water/kg dry matter), M_{t+dt} is the moisture content at $t+dt$ (kg water/kg dry matter) and t is the drying time (min).

The drying tests used 10-kg batches of fresh corn and were performed in triplicate at 30, 40, 50 and 60°C drying temperatures were chosen based on information found in the literature.

Colour measurement: A colourimeter (MSEZ-4500L, HunterLab, Virginia, USA) was used to measure the colours of fresh and dried corn samples. The colours were expressed as L*-values (lightness), a*-values (redness/greenness) and b*-values (yellowness/ blueness). The colourimeter was calibrated on a standard white plate before each colour measurement. A glass cell with a diameter close to that of the nose cone of the colourimeter, containing a sample, was placed above the light source, and the L*, a* and b* colour values were recorded [2]. The reading was performed on the external surface of the sample, and the mean of three readings at random locations on the sample was reported by Cheng *et al.* [39]. The chromaticity coordinate a* measures red when it is positive and green when it is negative, and the chromaticity coordinate b* measures yellow when it is positive and blue it is when negative. Additionally, the chroma C [Eq. (3)] and the hue angle α [Eq. (4)] were calculated from the values for $L * a * b$ and used to describe the colour change during drying [31, 37, 40]:

$$C = \sqrt{(a^2 + b^2)} \quad (3)$$

$$\alpha = \tan^{-1}\left(\frac{b}{a}\right) \quad (4)$$

Structural analysis: The microstructures of fresh and dried corn kernels were examined using a scanning electron microscope (Carl Zeiss/EVO 40, Oberkochen, Germany). The samples were fixed on the SEM stub and were subsequently coated with gold-palladium to provide a reflective surface for the electron beam [41]. The gold-palladium coating was conducted in a sputter coater (BALTEC SCD-005, Wetzlar, Germany) under a low vacuum (20 kV) in the presence of the inert gas, argon [42].

Statistical analysis: The results were subjected to an analysis of variance (ANOVA) using the MINITAB (Version 14, University of Texas, Austin, TX, USA) software. A least significant difference (LSD) test was used to establish multiple comparisons of the mean values at a 1% level of significance. All of the experiments were performed in triplicate.

Results and Discussion

Drying kinetics of dried corn: The moisture content versus drying time curves for the hot-air drying of dent corn as affected by various air temperatures are shown in Fig. 1. It is clear that the moisture content decreases continuously with the drying time [43, 44]. The experimental results showed that the total drying times required to dry corn kernels from an initial moisture content of 0.34 (kg water/kg dry matter) dry basis to a final moisture content of 0.11 (kg water kg/dry matter) dry basis were 400, 600, 800 and 900 min at the air temperatures of 30, 40, 50 and 60°C, respectively. The increases in the air temperature resulted in decreases in the drying time. Similar results have been reported in drying studies on eggplant [28], bay leaves [43], hull-less seed pumpkin [44], okra [45] and red pepper [46].

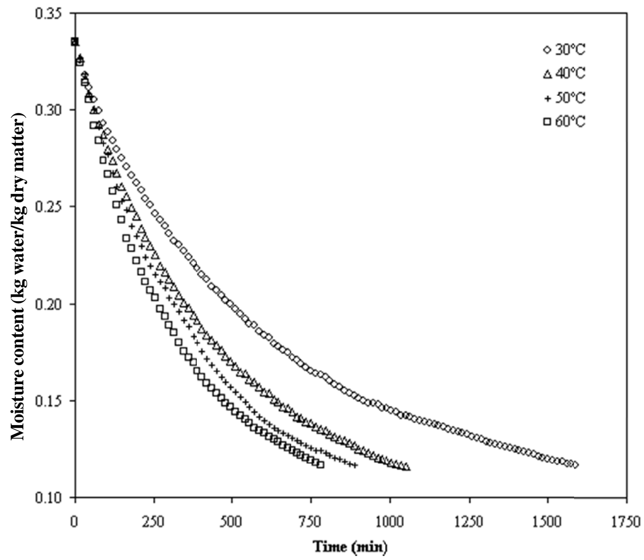

Figure 1. Moisture content drying curves of dent corn versus drying time at different temperatures.

The moisture ratio and drying rate of bay leaves versus the drying times at various drying temperatures are illustrated in Figs 2 and 3. As can be observed, there is no constant drying rate period in the drying of corn. This observation is in agreement with the results of studies on wheat [22], red pepper [46], apricot [47], mango [48], red chillies [49] and bay leaves [50]. The absence of a constant-rate period occurred because the product did not provide a constant water supply for an appreciable period of time. This lack was due to the rapid drying of the product during the initial stages of drying [51, 52].

The results show that all of the drying processes occurred in the falling-rate period, with the exception of a very small amount that occurred in the heating-up period. The results were generally in agreement with several literature studies on the drying of various food products [38, 53, 54]. As expected, higher drying rates were obtained with higher temperatures, and the highest values of the drying rate were determined during the experiment with an air temperature of 60°C. Similar results have been reported by many researchers [36, 46, 55, 56]. Additionally, at the beginning of the drying process, when the moisture content was high, the drying rate was very high, and as the moisture content approached the equilibrium level, the drying rate became very low [49, 57, 58].

As observed in Figs 1-3, one of the main factors influencing the drying kinetics of the corn kernels is the air temperature, which was also noted in other studies [28, 43, 59, 60].

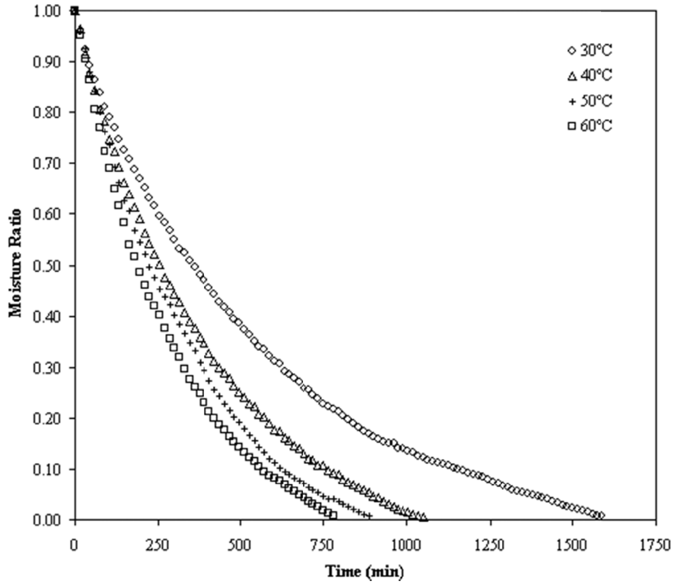

Figure 2. Moisture ratio drying curves of dent corn with drying time at selected temperatures.

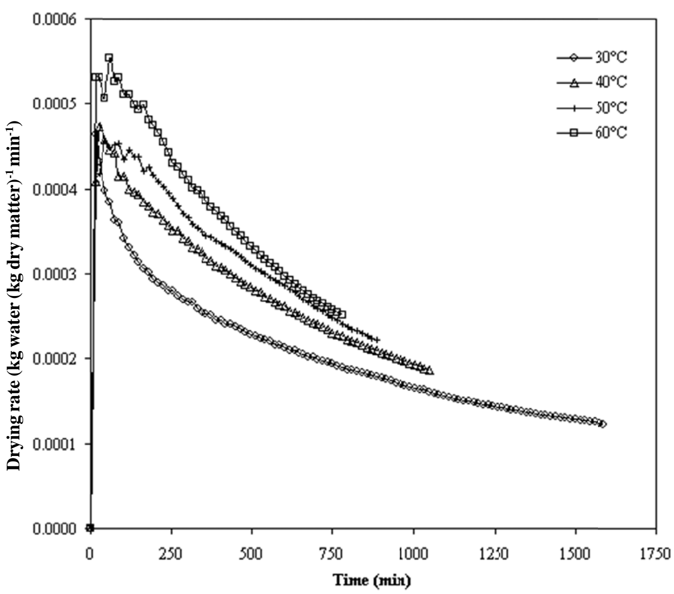

Figure 3. Variation of drying rate as a function of drying time at selected temperatures.

Colour analysis: Colour is an attribute that is important to the quality of a material [61]. Undesirable changes in the colour of food may lead to a decrease in its quality and marketing value [24]. The colour of corn kernels can differ considerably, ranging from white to yellow, orange, red, purple, and brown [62]. The results of colour measurements on fresh and dried corn at different drying temperatures are shown in Fig. 4. The lightness (L^*), yellowness/blueness (b^*), chroma (C) and hue angle (α) values of all of the samples decreased from 63.93 to 55.63, 36.93 to 28.96, 37.33 to 30.46 and 81.67 to 71.99, respectively. However, the redness/greenness (a^*) value increased from 5.43 to 9.44. All of the colour values of the fresh dent corn differed significantly from the values of the dried dent corn (P<0.01). Among all of the drying conditions used for corn samples, the closest values to the colour of the fresh beans were obtained at 30°C. It was observed that the lightness, L^*, for the dent corn decreased with an increase in

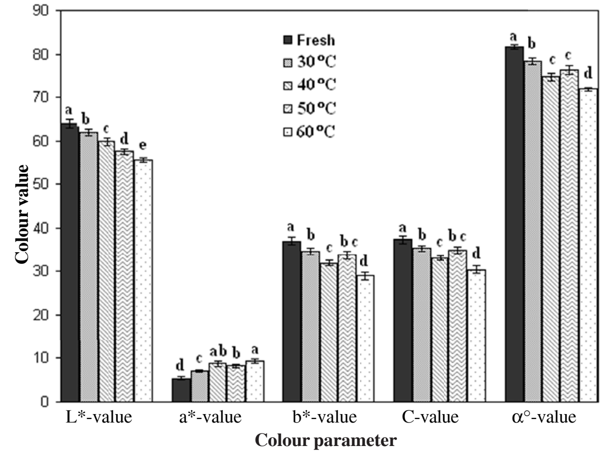

Figure 4. Colour values of fresh and dried corn at different hot air drying temperatures.

temperatures for all of the drying conditions. This finding indicated that the lightness (L^*) was inversely correlated with the temperature. Arslan and Özcan [63] reported that temperature exerts a significant effect on the colour of pepper slices. They found that the L^* values of the pepper slices decreased with oven (50°C and 70°C) drying. Additionally, Karabulut *et al.* [64] determined that the colour parameters were affected significantly by the drying temperatures in apricot drying. The decrease in the L^* values can be attributed to the formation of brown pigment during drying [63]. It is clear that browning increases with an increase in drying temperature [65-67].

Microstructural changes: Scanning electron microscopy (SEM) images of the fresh and dried corn obtained using different drying temperatures are shown in Fig. 5. There were no clear differences among the SEM images of fresh corn and corn dried at 30°C and 40°C temperatures in a hot-air dryer in terms of the granular integrity of the starch structures, but high temperatures (50°C and 60°C) during the drying process caused a more violent evaporation of water and melted the starch granules. This phenomenon could weaken the starch-protein matrix, causing structural damage and destroying the samples. These results were comparable to the findings in the literature [14, 41, 68, 69] and were consistent with the effects of high temperatures on the structures of dried products. This damage may be due to the shorter drying time, the higher drying temperatures and the tissue expansion from internal water vapour.

Conclusions

The effect of temperature on the batch drying of corn using hot air was studied. Increasing the temperature caused a significant decrease in the drying time. The drying process occurred in the falling-rate period, with the exception of a very small amount that occurred in the heating-up period. All of the colour values of the fresh corn differed significantly from the values of the dried corn (P<0.01). Among all of the drying conditions used for corn samples, the closest values to the colour of fresh corn were obtained at 30°C. It is clear that browning increases with an increase in drying temperature. Scanning electron microscope images showed that there were no clear differences among the SEM images of fresh corn and corn dried at 30°C and 40°C temperatures in a hot air dryer in terms of the granular integrity of the starch structures, but high temperatures (50°C and 60°C) during the drying process

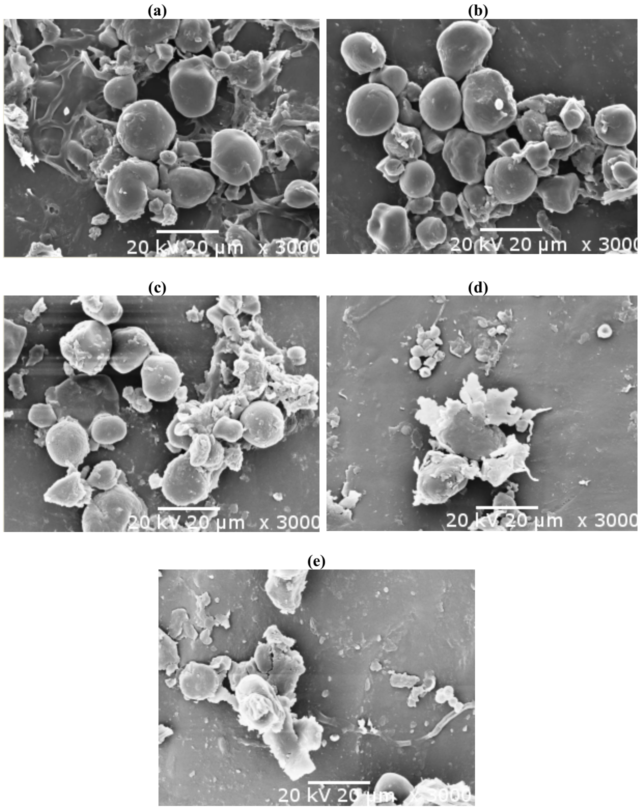

Figure 5. Scanning electron micrographs of fresh dried corn samples: (a) fresh, (b) hot air drying at 30°C, (c) hot air drying at 40°C, (d) hot air drying at 50°C (e) hot air drying at 60°C.

caused a more violent evaporation of water and the melting of the starch granules.

Acknowledgements

The authors thank the Uludag University Research Foundation for their financial support (Project No. UAP(Z) 2009/15).

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