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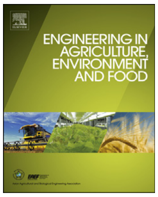

Quality assessment and kinetics of dehydrated watermelon seeds: Part 1

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ABSTRACT

Processing watermelon seeds has recently attained great attention in industry from two aspects of snack and high quality oil productions. Hence, in the first phase of our research, studying their drying kinetics, color quality in terms of L* a* b*, total color difference (ΔE), chroma and Hue angle and germination vigor of watermelon seeds were studied experimentally in detail with three drying air temperatures (40, 50 and 60 °C) along with three levels of air velocity (0.5, 1 and 1.5 $\mathrm{m\ s^{-1}}$). It was concluded that well-known Verma et al. thin layer drying model was greatly superior for prediction of watermelon seed drying kinetics in most cases while the effective moisture diffusivity of seeds was found ranging between 3.009×10^{-10} and 6.805×10^{-11} $\mathrm{m^2\ s^{-1}}$ and the energy of activation was evaluated between 37.11 and 56.63 $\mathrm{kJ\ mol^{-1}}$. It was also inferred that air temperature level more profoundly affected the color and germination of the seeds than velocity while to maintain color quality and germination vigor high, the convectively drying temperatures should not exceed 50 °C.

1. Introduction

Preserving seeds of agricultural products against deterioration is a big problem in agriculture. Moreover, the conventional cheap open sun drying of seeds has also adversely affected the quality of seeds in terms of color and viability while insects' infestation and the hygienic - related problems have highlighted the great significance of utilizing a dryer and setting the drying conditions correctly for better gains. As good seed quality directly affects the success of crops and contributes significantly to enhance productivity levels, high-quality seed production is a challenge for the agricultural sector (Barrozo et al., 2014). Generally, the term thin layer drying refers to the grain drying process in which all grains are fully exposed to the drying air under constant drying conditions while all commercial flow dryers are designed on thin layer drying principles. Hence, thin layer is believed to be the best criteria for the simulation of food drying processes (Aghbashlo and Samimi-Akhijahani, 2008). Internationality, numerous studies have sought to model or describe the thin layer drying process of seeds. Mathematical modeling of thin layer drying of papaya seeds was considered for finding the appropriate drying conditions including three different temperatures each accompanied by three different velocities of air (Mocelin et al., 2014). Drying kinetics of seeds of three kinds of grape undertaking three different temperatures with a constant air velocity was also studied in detail and the corresponding effective moisture diffusivity and activation energy parameters were found. Moreover, the Lewis model as the excellent model for predicting all three grape seed was proposed (Roberts et al., 2008). Besides, the thin layer drying of melon seeds was studied through using five desorption isotherm and three thin layer drying models while it was found that the exponential model is adequate enough for predicting thin layer drying of melon seeds (Ajibola, 1989). A method for determination of temperature dependent moisture diffusivities of pumpkin seeds through natural and forced convection drying processes was also proposed. Therefore, the pumpkin seed particles were considered as of rectangular prisms with specified dimensions while execution of written computer program through the iterative technique led to specification of coefficient of diffusivity of the given seeds (Can, 2007). Many other studies are also performed for drying other

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Nomenclature

M	Moisture content (db%)
D_{eff}	Effective moisture diffusivity (m^2s^{-1})
T	Time (s)
MR	Moisture ratio (−)
L	Half thickness of the slab (watermelon seed) (m)
N	Positive integer (−)
M_t	Moisture content at any time (db%)
M_0	Initial moisture content (db%)
M_e	Equilibrium moisture content (db%)
D_0	pre-exponential factor of the Arrhenius equation (m^2s^{-1})
E_a	Activation energy (J mol^{-1})
R_g	Universal gas constant (J mol^{-1} K^{-1})
T	Absolute air temperature (K)
V	Hot air velocity (m s^{-1})

agricultural seeds (wheat seed (Hemis et al., 2012), grape seed (Johann et al., 2016), barley grain (Markowski et al., 2007), canola seed (Hemis et al., 2015), hass avocado seed (Avhad and Marchetti, 2016), amaranth seed (Abalone et al., 2006)) among which watermelon hot air seed drying has been scarcely investigated except for an infrared drying study of watermelon seeds conducted by Doymaz (Doymaz, 2014) who applied different levels of infrared power to evenly and homogenously spread seeds on a pan. From the other side, based on the latest statistics released by Food and Agriculture Organization (FAO) watermelon-pertaining worldwide production could reach in excess of 182, 121, 406 metric tons by 2014 mainly produced by China, Iran, Turkey, Brazil, respectively while Iran's watermelon production share amounted to 3,947,057 metric tons (Food and Agriculture organization of United Nations statistics, 2016. FAOSTAT. http://www.fao.org/faostat/en/#home (accessed 12.07.2016)) whereas a major portion of watermelon production in Iran is only devoted to its seed production (Moradi et al., 2015). From the other side, watermelon has a water content of about 95% which makes it highly susceptible to deterioration (Falade et al., 2007) and poses the microbial spoilage threat to its seeds while dehydration as a conventional technique may seem useful for their preservation and extension of their shelf-life (Doymaz, 2014). Moreover, drying methods considerably affect the color, texture and porosity of the dehydrated materials (Chen et al., 2005). Based on the above mentioned points of significance and meeting the need for designing and fabrication of a high capacity industrial watermelon seed dryer in future (part 2), it was necessary to do the related experiments in a laboratory scale work and specify the crucial values for role-playing parameters. Hence, the effects of two parameters of drying air velocity and temperature on changes of color quality of seeds during drying, germination vigor of given seeds for possible planting and finally the drying kinetics of watermelon seeds were all investigated.

2. Materials and methods

2.1. Seed sample preparation

Watermelons (Citrullus vulgaris variety) were obtained from a farm in Miyan Jolgeh district (Nishabur county, Razavi Khorasan Province, Iran). Their seeds were collected manually and washed to remove the remaining watermelon pomace and were blotted instantaneously with tissue paper to eliminate excess water on the surface. Afterwards, they were immediately put on trays and loaded into the dryer.

2.2. Moisture content determination

To determine the initial moisture content (M_0) of watermelon seeds, 60 g of seeds (three samples of each 20 g) were weighed with an electronic balance of 0.01 g precision and laid inside an oven (D06062, Model 600, Memmert, Deutschland) at 105±1 °C for 24 h. This step was replicated at least twice prior to beginning drying test. The average initial moisture content of samples was gained 49.93 (wb%).

2.3. Drying conditions and experimental set-up description

To conduct the drying experiments, a laboratory-scale hot air dryer equipped with instrumentations was fabricated (Fig. 1). The dryer includes main components of air blower, electrical heaters, honeycomb, drying trays, dedicated balance and finally an automatic control unit. To supply air flowing through drying chamber a blower being rotated by a 2 hp 3-phase motor was used. This air velocity was measured at 9 points using an anemometer (LT lutron, LM-81AM, ± 0.1 m s^{-1}, Lutron Electronic Enterprise Co., Ltd., Taipei, Taiwan) at the outlet and the mean value was reported as the velocity of air. Hence, the motor rotation speed was regulated to readily achieve the desired air velocities of 0.5, 1 and 1.5 m s^{-1}. Meanwhile, to supply enough thermal energy for heating up the inlet drying air, three electrical elements (2 with 2500 W and 1 with 1500 W electrical power) were used. These electrical elements enabled regulation of air temperature through being continuously switched on and off by a temperature controller (Autonics TZ4ST-14R, ±0.3%, Autonics Corporation, Gyeonggi-do, Korea) until the desired level of temperature (40, 50 and 60 °C) was gained. The heated air passing through honeycomb would reach drying chamber which included three drying sieves each displaced 0.075 m. A digital balance (Kern 572-57, ±0.1 g accuracy, KERN & Sohn GmbH, Balingen, Germany) was used for measuring the sample weights. This balance was placed on top side of the drying chamber with stainless steel rods suspended from it inside the drying chamber hanging sieves which enabled recording the sample weight losses throughout the drying process at 10 min intervals without interruptions.

To measure the relative humidity of hot drying air inside drying chamber a humidity meter (SAMWON ENG SU-503B, ±1%, Korea) was also used. The humidity and temperature sensors were all installed in drying chamber to monitor the ongoing changes.

2.4. Experimental procedure

Prior to beginning the drying experiments, stabilized conditions, in terms of temperature and air velocity, were achieved inside the drying chamber. For each drying condition, about 180 g of watermelon seeds were spread uniformly in a single layer on three sieves (about 60 g/sieve) inside drying chamber. The desired levels of hot air temperature (40, 50 and 60° C) along with three air velocities (0.5, 1 and 1.5 m s^{-1}) were carefully provided to record the sample moisture changes while the relative humidity inside the chamber was also recorded throughout the tests. Drying continued until the mass difference between the two consecutive weighing was less than 0.05 g.

2.5. Theoretical analysis of experimental data

2.5.1. Effective moisture diffusivity

Drying most agricultural products occurs in the falling rate period. Fick's second law of diffusion, as shown in Eq. (1), has been

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