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Studies of vegetable drying process in infrared film dryer

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Abstract. The research work analyzes the two fresh vegetable (carrot and garlic slices) drying process in the infrared film dryer. The energy of infrared radiation penetrates through the material and is converted into heat, and the temperature gradient within the product is reduced in a short period of time. Infrared drying takes place at low temperatures (up to 35 °C) and it helps keep the maximum product quality and natural color. The vegetable drying rate significantly differs depending on the location of the products in relation to the infrared film and product location at the air inlet and outlet. With dried products in 3 parallel shelves the most rapid removal of moisture occurs in the lower shelf (close to the air inlet and film) and the top shelf (close to the air outlet and film). This difference compared to the middle shelf reaches 10–15%. Using the experimental data and multivariate analysis it has been found that the product moisture removal depends on its placement (at the heating film and air inlet, outlet) and the drying time.

Key words: IR drying, IR film, carrot, garlic

INTRODUCTION

Infrared drying (IR) is an effective method of dehydration. It is based on the fact that infrared radiation of certain wavelengths is actively absorbed by water contained in the product. The energy is applied directly to the water of the product, and this is achieved by high efficiency and economy. The absorptivity, the depth of material and the transmissivity are dependent on the IR wave length, density and the properties of the irradiated material.

In the past drying was performed with less emphasis on the quality of the dried products but at the present the quality becomes much more important. Nowadays, we can evaluate the quality of dried products such as texture, color, flavor, nutritional content etc. Drying temperature 40–60 °C is optimal to preserve vitamins, biologically active substances, natural color, flavor and aroma of the dried products. Paakkonen et al. (1999) have shown that IR drying improves the quality of herbs. Pan et al. (2005), Sharma et al. (2005) studied the quality characteristics and advantages of onion infrared drying with different drying temperatures and inlet air velocities. Aboltins and Palabinskis (2016) analyzed three different product (apple, banana slices and grape halves) drying process in the IR film dryer, Prabhanjan et al. (1995) investigated thin layer carrot microwave assisted convective drying,

Carrots *(Daucus carota)* play an important role in human diet because they have one of the highest levels of β-carotene, besides being rich in B vitamins, fiber and minerals (Prakash et al., 2004). In regard to β-carotene, (Bao & Chang, 1994) cite the carrot as the food with the highest level of this nutrient. The drying of carrot in microwaves has been studied under different aspects. The physical properties and the influence of power ratings on the content of β-carotene was evaluated (Bettega *et al*., 2014), color changes at drying temperatures 50–80 °C was evaluated (Li et al., 2010). Infrared drying characteristic of carrot was investigated in the temperature range of 50–80 °C (Toģrul 2005).

Nowadays, garlic presents a growing interest due to its capacity to form allicin, a powerful antioxidant. Studies have shown that allicin is a natural weapon against infections and is helpful in preventing heart disease and other health disorders (Ankri & Mirelman 1999). Research revealed that drying temperature and thickness of garlic slices significantly affected on color and rehydration ration (Ponciano, 2007).

Dehydration is an important processing operation in the food industry. However, it is well known that the quality of a dehydrated food product is strongly affected by the drying process characteristics (Cui et al., 2003).

Drying can cause changes in the physical properties such as color and structure, as well as the deterioration of aroma compounds or degradation of the nutritional substance reducing the product quality. High drying temperatures reduce the nutrients, aroma, change color, and cause vitamin losses.

The present paper examines the IR film drying possibilities with small heating up to 40 °C. There investigates and compares two products (carrot and garlic slices) drying dynamics depending on the distance from the IR source (film) and the distance from the inlet and outlet of air in the dryer.

MATERIALS AND METHODS

The experiment was conducted at the Grain Drying and Storage Scientific Laboratory at the Latvia University of Agriculture.

The infrared (IR) dryer (Fig. 1) consisted of a drying chamber (80 x 55 x 75 cm) with a heat source IR film (South Korea EXCEL). The drying equipment body from the inside from all sides was insulated with putupolistorolu and aluminium foil. It increases the drying efficiency by reducing heat losses to the environment. The infrared film with a thickness of 0.338 mm was located on the aluminium foil along the perimeter of the drying chamber. The applied film power was 150 W m^{-2}. The maximum temperature on the surface of the film reaches 45 °C.

The drying chamber shelf system can accommodate up to eight shelves, depending on the amount of the drying material (Fig. 2). Shelving is adjustable relative to the upper and lower heating elements and is interconnected with the screw nut. The screw nut adjustment allows for easy shelf height change through various studies. The studies were conducted with three shelf systems and the first plate was located 10 cm from the lower heating element, the second - 35 cm and the third - 60 cm or 15 cm from the upper heater (Fig. 3).

Figure 1. IR dryer shelving system.

Figure 2. IR dryer with carrot in practice.

Air supply is held by eight adjustable variable cross-section holes that are below the shelf level. The experiments were performed with the fan with a total maximum capacity of 100 m^3/h and power 19 W, which is placed on the top of the side wall of the equipment (Fig. 3).

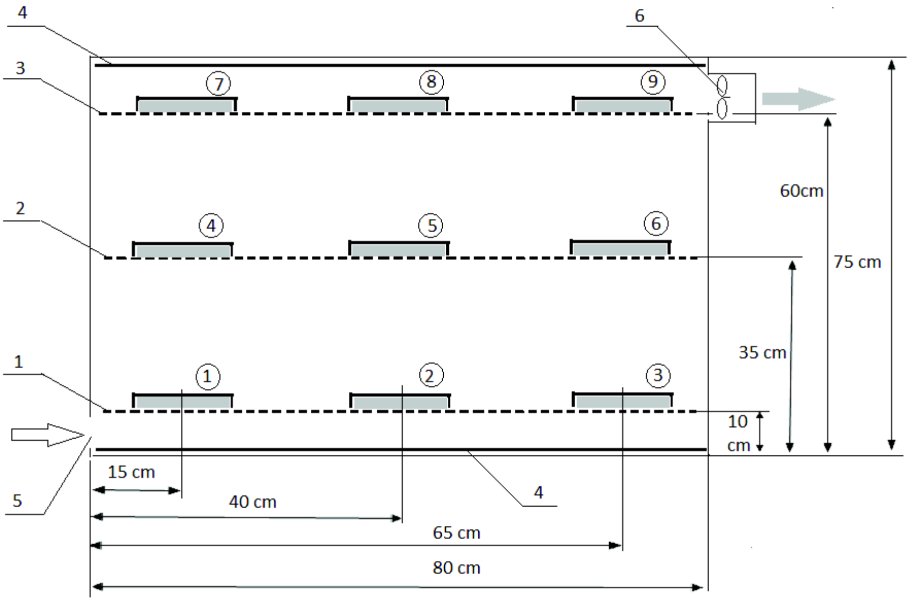

Figure 3. Schematic view of IR dryer: 1, 2 and 3 – Shelves; 4 – IR drying film; 5 – Air inlet holes; 6 – Fan.

The carrots were cut into 1 cm thick slices, garlic was cut in half crosswise 1 cm thick (Figs 4 and 5).

The samples were placed on a round drying tray (diameter 20 cm), which consisted of a fine mesh aluminium screen with a plastic frame Fig. 4. These sample plates were put on the drying chamber trays. The trays were placed 10 cm, 35 cm and 60 cm from the IR film on the bottom and 15, 40 and 65 cm from the air inlet (Fig. 3).

Figure 4. Garlic cloves before drying.

Figure 5. Carrot slices after drying.

The moisture content in the material was identified by gravimetric measurement in time intervals. The samples were weighed on the digital laboratory balance KERN-440-35N with maximum load weight 400 g and with resolution 0.01 g. The total drying time was 24 hours. The initial moisture content of carrot and garlic was 87.2% and 62.1% corresponding.

The average inlet air temperature during the experiment was 18.5 ± 0.5 °C with average humidity 47.3%. The dry matter is determined by laboratory equipment Memmert, drying the product at 102 °C to constant weight of the product.

The experimental data were processed with the program packets MathCad and MatLab.

RESULTS AND DISCUSSION

Our interest was to find out the carrot and garlic drying efficiency dependence on the position in the drying equipment. Two cases were studied: material moisture dependence on the drying time and the distance from the inlet holes and material moisture dependence on the drying time and the distance from the IR film.

The experimental data show that the outlet air temperature was on average 11 degrees higher than the inlet air temperature during the experiment. Nonlinear multivariable equations between the material moisture M(t, x), drying time t and the distance from the inlet holes at various shelf heights were obtained.

For carrots:

Distance from the IR film on the bottom 10 cm,

$$M(t,x) = 80 - 0.083 \times t + 2.147 \times 10^{-5} \times t^2 + 0.54 \times x - 6.61 \times 10^{-3} \times x^2 + 1 \times 10^{-5} \times t \times x; \quad (1)$$

Distance from the IR film on the bottom 35 cm,

$$M(t,x) = 84.9 - 0.062 \times t + 1.18 \times 10^{-5} \times t^2 + 0.233 \times x - 2.8 \times 10^{-3} \times x^2 + 1.37 \times 10^{-4} \times t \times x; \quad (2)$$

Distance from the IR film on the bottom 60 cm,

$$M(t,x) = 85 - 0.081 \times t + 1.96 \times 10^{-5} \times t^2 + 0.424 \times x - 6.21 \times 10^{-3} \times x^2 - 2 \times 10^{-5} \times t \times x; \quad (3)$$

For garlic:

Distance from the IR film on the bottom 10 cm,

$$M(t,x) = 62.2 - 0.039 \times t + 8.14 \times 10^{-6} \times t^2 - 0.08 \times x - 1.13 \times 10^{-3} \times x^2 + 3.87 \times 10^{-5} \times t \times x; \quad (4)$$

Distance from the IR film on the bottom 35 cm,

$$M(t,x) = 59 - 0.037 \times t + 7.85 \times 10^{-6} \times t^2 + 0.186 \times x - 2.14 \times 10^{-3} \times x^2 + 3.34 \times 10^{-4} \times t \times x; \quad (5)$$

Distance from the IR film on the bottom 60 cm,

$$M(t,x) = 58.6 - 0.042 \times t + 9.9 \times 10^{-6} \times t^2 + 0.169 \times x - 1.94 \times 10^{-3} \times x^2 - 2.7 \times 10^{-5} \times t \times x, \quad (6)$$

where: M(t, x) – material moisture, %; t – drying time, min; x – distance from the air inlet, cm.

The coefficient of determination in these cases was $R^2 = 0.99$. Graphically we compare the carrot and garlic drying dynamics in the case when the products are placed on the top shelf (equations (3) and (6)) Figs 6a and 6b.

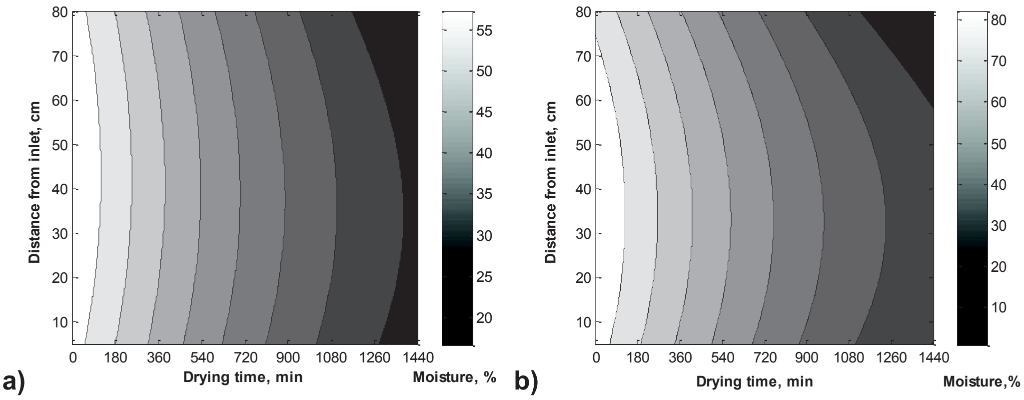

Figure 6. Drying time and distance from air inlet influence on **garlic** (a) and **carrot** (b) drying dynamics on top shelf.

As it can be seen, the fan closeness significantly accelerates the drying of the product, especially it is seen at the carrot drying. It can be seen that the air inlet closeness affects the drying rate. This could be explained by a flow of air having less moisture content. The slowest drying took place in the middle of the dryer at all distances of the IR film used in the experiment. As it can be seen from the equations (1)–(6) the drying time is the key parameter that affects the drying dynamics and it is lower in the middle. Its effect in the middle is up to 20% less (for carrots) than at the edges (at the air inlet and outlet) (Fig. 6b).

The experimental results showed that the water removal from the vegetables in the middle shelf was about 10–15% lower than that of the upper and lower shelf.

The distance from the IR film also affect the moisture removal from the material. We tested the effects of 3 different locations, depending on the distance (15, 45, and 65 cm) to the air intake vents. It should be noted that the IR film was on the bottom and top (75 cm from the bottom) in the dryer.

For carrots:

Distance from the air inlet 15 cm,

$$M(t, y) = 81.3 - 0.077 \times t + 1.8 \times 10^{-5} \times t^2 + 0.492 \times y - 6.05 \times 10^{-3} \times y^2 - 5.8 \times 10^{-6} \times t \times y; \quad (7)$$

Distance from the air inlet 45 cm,

$$M(t, y) = 85.8 - 0.061 \times t + 1 \times 10^{-5} \times t^2 + 0.153 \times y - 1.52 \times 10^{-3} \times y^2 - 7.7 \times 10^{-5} \times t \times y; \quad (8)$$

Distance from the air inlet 65 cm,

$$M(t, y) = 86 - 0.089 \times t + 2.5 \times 10^{-5} \times t^2 + 0.28 \times y - 4.22 \times 10^{-3} \times y^2 - 3.6 \times 10^{-5} \times t \times y; \quad (9)$$

For garlic:

Distance from the air inlet 15 cm,

$$M(t, y) = 60 - 0.039 \times t + 8.6 \times 10^{-6} \times t^2 + 0.1 \times y - 1.6 \times 10^{-3} \times y^2 - 2.98 \times 10^{-5} \times t \times y; \quad (10)$$

Distance from the air inlet 45 cm,

$$M(t, y) = 58 - 0.037 \times t + 8.47 \times 10^{-6} \times t^2 + 0.316 \times y - 4.47 \times 10^{-3} \times y^2 - 2.2 \times 10^{-5} \times t \times y; \quad (11)$$

Distance from the air inlet 65 cm,

$$M(t, y) = 59 - 0.035 \times t + 8.58 \times 10^{-6} \times t^2 + 0.245 \times y - 3.6 \times 10^{-3} \times y^2 - 9.4 \times 10^{-5} \times t \times y, \quad (12)$$

where: M(t, y) – material moisture, %; y – distance from the bottom with the IR film, cm.

Graphic comparison of the obtained equations (7)–(12) is shown in Figs 8 and 9.

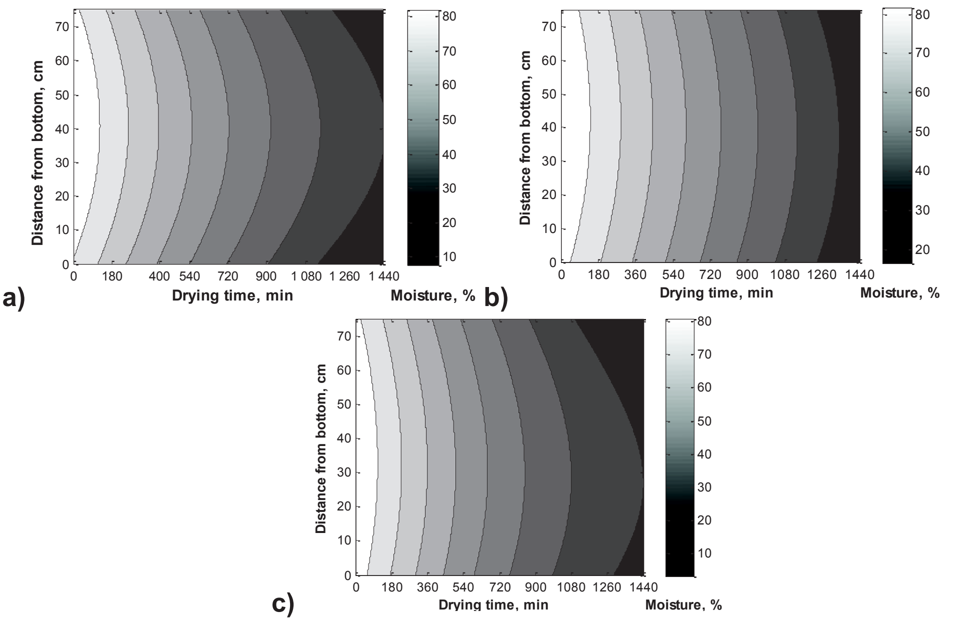

Figure 8. Drying time and distance (from IR dryer bottom) influence on water removal from **carrots**: a) 15 cm from air inlet; b) 45 cm from air inlet; c) 65 cm from air inlet.

These graphs show the effect of the direct distance to the film. The fan effect is shown in Figs 8c and 9c. The upper IR film had greater effect on moisture removal. It might be explained by aluminium basis of the trays. For IR rays it is harder to warm the product.

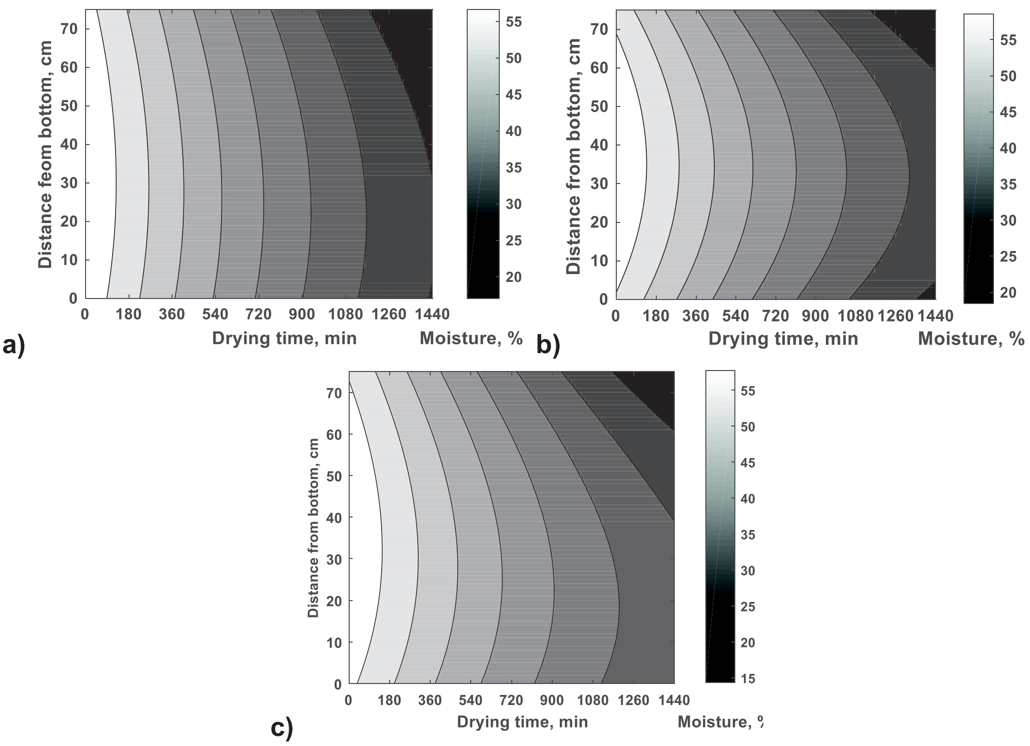

Figure 9. Distance (from IR dryer bottom) and drying time influence on water removal from **garlic**: a) 15 cm from air inlet; b) 45 cm from air inlet; c) 65 cm from air inlet.

CONCLUSIONS

The study shows that drying using the IR film is suitable at low temperatures (up to 35 °C) and it helps to maintain the maximum product quality and natural color. The vegetable drying rate is significantly different depending on the location of the products in relation to the infrared film and product location at the air inlet and outlet. With dried products in 3 parallel shelves it was found that the most rapid removal of moisture occurs in the lower shelf (close to the air inlet and film) and the top shelf (close to the air outlet and film). This difference compared to the middle shelf reaches 10–15%.

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