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AN ENERGY EFFICIENT CORN GRAINS DRYING PROCESS

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Preliminary notes

A laboratory laser beam drying method for corn grain kernels is presented and the corresponding energy transfer is analysed. The proposed drying method enables fast and efficient decrease in grain humidity while preserving grain sprouting. Laser beam was directed to the thin grain layer with powers of 10 kW/m^2 and 20 kW/m^2. Grains were illuminated from one side during a period of 30 s with 100 mW, 655 nm and 200 mW, 660 nm collimated laser beam. The method exhibits at least an order of magnitude higher energy transfer compared to the classical drying method that uses hot air as drying medium. The energy savings increase, compared to classical hot air drying, both in laboratory conditions, was between 23,56 and 58,70 % (100 mW laser) and 10,62 % (200 mW laser), depending on grain wet basis and decreasing with decrease of moisture content.

Keywords: *corn grain wet basis, energy efficiency, energy transfer, grain illumination, hot air drying, laser beam drying*

Energetski učinkovit proces sušenja kukuruznog zrna

Prethodno priopćenje

Ovaj rad analizira metodu sušenja zrna kukuruza laserskim zračenjem u laboratorijskim uvjetima i prijenos energije tijekom procesa. Predložena metoda sušenja omogućuje brzo i učinkovito smanjenje vlažnosti zrna pri čemu ne dolazi do oštećenja reproduktivnog dijela zrna. Elementarni (tanki) sloj zrna tretiran je laserskom svjetlošću snage 10 kW/m^2 i 20 kW/m^2. Zrna kukuruza osvjetljivana su s jedne strane tijekom 30 sekundi sa 100 mW laserom valne duljine 655 nm i 200 mW laserom valne duljine 660 nm. Postupak sušenja laserskim zračenjem pokazuje veći prijenos energije u odnosu na klasični postupak sušenja korištenjem vrućeg zraka. Uštede u potrošnji energije ostvarene u laboratorijskim uvjetima u odnosu na klasični način sušenja zagrijanim zrakom, iznosile su između 23,56 i 58,70 % (100 mW laser) i 10,62 % (200 mW laser), ovisno o vlažnosti zrnatog materijala. Snižavanjem vlage materijala došlo je do smanjenja količina energije potrebne za sušenje.

Ključne riječi: *energetska učinkovitost, osvjetljenje zrna, prijenos energije, sušenje laserskim zračenjem, sušenje vrućim zrakom, vlažno kukuruzno zrno*

1 Introduction

The main issue in contemporary corn grain drying process is the energy consumption used for conventional hot air drying process. High energy consumption is still necessary in food production, such that total power consumption for a hectare of corn amounts to 26 600 MJ, including energy consumption needed for grain cultivation and machine alimentation. Its conservation demands an additional 10 250 MJ of energy for drying [1, 2], which leads to about 25 % of energy consumption on the side of grain conservation.

Compared with about 8000 kg of dry corn grain with 16,8 MJ/kg corn or about 134 000 MJ/ha corn that is energy equivalent of corn grain produced in one hectare, its production still gives about 3,5 times higher energy yield. According to Katić [2] and Meierinf et al. [3] typical energy consumption in existing convectional industrial dryers can range from 3500 kJ to 7000 kJ (with average consumption of 4200 kJ) for 1 kg of evaporated water, depending on the construction of the equipment and the dried material.

The other issues are dominantly the use of fossil fuels that are environmentally harmful as well as energy loss in hot air conducts. Thus high energy demand for corn grain conservation either at the grain reception time in silo, where its wet basis is rather high attaining up to 25 % of moisture, or later on in cyclic grain retreatment, where its wet basis moisture amounts to about 14 %, leaves enough space for energy savings. Drying is a complex process that involves heat and mass transfer phenomena and is frequently used in food processing industry [2, 4]. It is probably the main and the most expensive step after harvesting. Mathematical modelling and simulation of drying curves under different conditions is important in order to obtain better control of this unit operation and overall improvement of the quality of the final product. The study of drying behaviour of different materials has been a subject of interest for various investigators from both theoretical and practical perspective. In the course of studies conducted regarding the drying behaviour of various agricultural products, many mathematical models have been used to describe the drying process. The thin-layer drying models are the most common ones [5]. Thin-layer drying equations are used to estimate drying time of several products and also to generalize drying curves. Several investigators have proposed numerous mathematical models for thin layer drying of many agricultural products. Average moisture ratio can be calculated by the Newton equation:

$$MR=\frac{M-M_e}{M_i-M_e}=\exp(-kt). \tag{1}$$

Page (1949) proposed the following empirical equation for shelled corn:

$$MR=\frac{M-M_e}{M_i-M_e}=\exp(-kt^n),, \tag{2}$$

where: MR = Moisture ratio, M_i = initial moisture content (% d.b.), M_e = equilibrium moisture content (% d.b.), M = instantaneous moisture content (% d.b.), t = drying time (s, min, h), and k and n are drying constants.

Equation (2) was frequently used by several researchers to determine the single-layer drying characteristics for agricultural products: barley [6], canola [7], corn [8], rice, rough [9], soybeans [10], sunflower (oilseed) [11], and wheat [12]. Hence, the Newton equation and the Page equation are applicable for mono-layer drying of cereal grains and other agricultural products. These two equations are also recommended by the American Society of Agricultural Engineers for single-layer drying of crops [13]. One way to save energy is to improve hot air dryer construction, by using different construction and isolation materials, and to improve the process by using energy recirculation and recuperation [1, 2]. The other way is to try another physical principle for drying process. That includes use of coherent light (laser) Near Infrared (NIR), radio frequency (RF), microwave and vacuum drying, where heat is supplied by conduction or radiation, while the vapour thus produced can be removed by the vacuum system [14]. Other potential applications requiring lower losses of electromagnetic radiation should therefore preferably use frequencies below optical phonon frequencies. The development of nanophotonic (nanolaser) devices requires the ability to confine and control light at scales much smaller than the wavelength of light. A shorter wavelength implies a smaller diffraction limit in the plane of propagation, and thus rapid exponential decay of the electromagnetic field away from the interface [15].

According to the preliminary data obtained by using laser beam stimulation of corn grains and obtained drying effects [16, 17], we have undertaken adequate laboratory experiments using laser treatment of corn grains at the most extended exposure time of 30 s for drying purposes that still preserves grain sprouting ability.

During the laser treatment, the energy couples directly to the material that is heated. It is not expended in heating the air, walls of the oven, conveyor, or other parts of equipment. Also, better and more rapid process control can be achieved. This can also lead to significant energy savings [18, 19].

Grain exposure time to laser stimulation greater than 30 s with focused laser beam of 1 mW has been shown as possibly destructive [16]. Another reason for investigating laser beam stimulation as drying procedure has been the observation of comparable stimulation for overall grain sprouting condition and decreased mycotoxic contagion after laser exposition [17]. Detailed impact of laser beam on grain structure is still unexplained, although the basic mechanism seems to consist of direct water molecule excitation in deeper grain structure.

2 Material and experimental method

2.1 Drying process in laboratory laser set-up

Fig. 1 shows a schematic diagram of the dryer with integrated laser diode net (3 × 5 lasers). It consists of drying chamber (with air output, air input and inspection window), and instruments for measurement (wet thermometer, dry thermometer and electronic balance). The drying chamber was constructed from stainless steel sheets with internal dimensions 300 × 300 × 400 mm. One tray was placed inside the drying chamber.

Laboratory tests were carried out on a single section of laser diode network. Laboratory laser set-up is as indicated in Fig. 2 [16, 20]. Kernels have to be put on illuminated area 10 cm in diameter under the laser source. Distance (LM) between laser source and micro-objective was 7 cm and distance (MK) between micro-objective and kernels was 32 cm.

2.1.1 Geometry

Vertically mounted laser source of 100 mW 655 nm and 200 mW, 660 nm, with a beam directed at the flint glass and thus extended to the glass plate of 100 mm diameter containing approximately 60 corn grains in a thin elementary layer; laser beam intensity at the grain level is approximately 10 kW/m^2, respectively 20 kW/m^2.

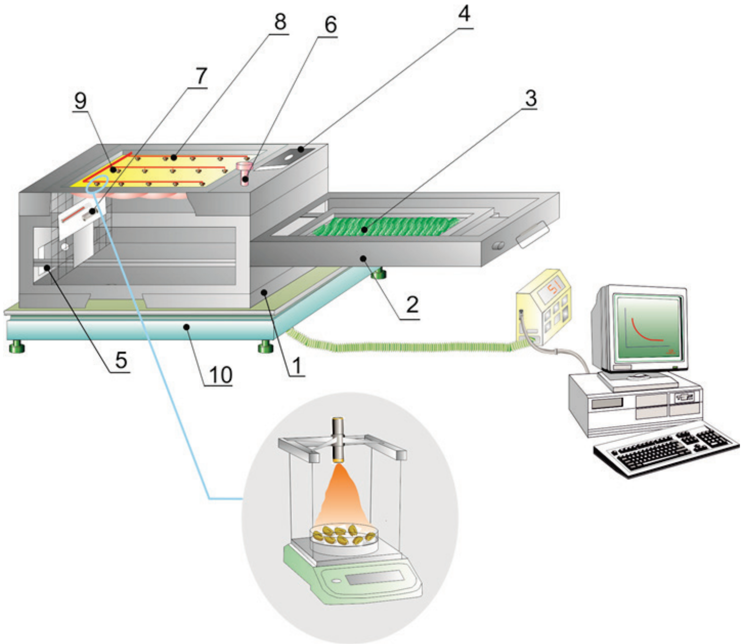

Figure 1 Experimental set-up of the drying process illumination with laser beam
(where: 1 – dryer, 2 - frame for biological material, 3 – biological material (stevia leaves), 4 – air output, 5- air input, 6 - thermometer (dry), 7 - thermometer (wet), 8 – inspection window, 9 - laser diode net, 10 - electronic balance)

2.1.2 Drying conditions

Laser beam is directed to each grain on the glass grain plate with equal power of approximately 10 kW/m^2, or respectively 20 kW/m^2. Grains are illuminated from one side during the controlled time duration. Time duration is chosen according to earlier experiences [21] and determined with an electronic stop watch. Grain plate is positioned on the laboratory analytical balance type with measurement accuracy class I scale interval 0,1 mg. During the drying process, laboratory environment humidity was between 45 % and 57 % and atmosphere pressure was in the mean 1035 hPa.

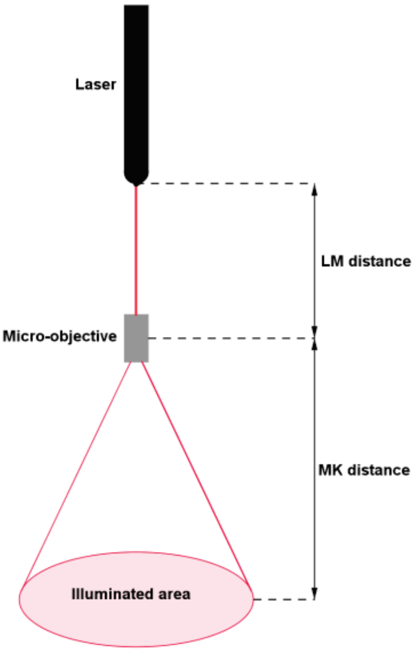

Figure 2 Experimental set-up of the grain drying process illumination with laser beam

2.1.3 Grain state at the beginning of the experiment

Moisture content of grain was preset with the following procedure: Samples to be tested have been cleansed from filth and ingredients. Only visually whole, healthy and undamaged kernels have been selected for treatment. Cleansing was done manually. The experiment was performed for different initial moisture content of kernels where particular initial moistures have been obtained by kernel conditioning. Conditioning was performed by adding distilled water to the grains. Distilled water was added for samples to achieve desired moisture content (≈14, 16, 18, 20, 22 and 24 %) according to the relation:

$$m_V = m_U \frac{W_2 - W_1}{100 - W_2}, \qquad (3)$$

where: m_V – amount of added distilled water (g), m_U – mass of samples (g), W_1 – initial moisture content (%) and W_2 – expected sample moisture content after addition of distilled water (%).

Grain (kernel) samples have been conditioned in hermetically sealed bottles kept at the temperature of about +5 °C (±1 °C) and periodically shaken to homogenize grains (kernels). This process lasted for seven days. Thus corn grains were fixed at the wet basis of 13,84 %, 15,68 %, 17,72 %, 20,51 %, 22,55 % and 24,46 % of moisture content.

2.1.4 Drying process

Grains were put from the wet conditioner place to the glass plate on the laboratory analytical balance and illuminated for a prescribed time with the previously mounted laser beam facility. During the drying process, reduction in the weight of the samples was measured using a precision balance and was recorded. Before and after the illumination, grain moisture was determined by a HRN ISO 6540:2002 procedure [22] in laboratory dryer INKO ST40T in the temperature range from 130 °C to 133 °C and at atmospheric pressure during 90 (60 + 30) minutes until the mass of the substance remains constant [20].

Table 1 Corn kernels and stevia leaves drying parameters

Sample	Moisture content (% w.b.)	Laser output power (mW)	Illumination period (s)	Expended energy (kJ/active surface)	Evaporated moisture (kg/elementary layer)	Energy for evaporation (kJ/kg)
Corn kernels	13,48	100	30	$2,76\times10^{-03}$	$1,87\times10^{-07}$	14726,59
		200	30	$5,52\times10^{-03}$	$2,03\times10^{-07}$	27127,94
	15,68	100	30	$2,75\times10^{-03}$	$3,59\times10^{-07}$	7657,23
		200	30	$5,51\times10^{-03}$	$3,84\times10^{-07}$	14326,44
	17,72	100	30	$2,75\times10^{-03}$	$5,60\times10^{-07}$	4902,27
		200	30	$5,49\times10^{-03}$	$4,95\times10^{-07}$	11083,37
	20,51	100	30	$2,72\times10^{-03}$	$8,52\times10^{-07}$	3193,86
		200	30	$5,44\times10^{-03}$	$9,03\times10^{-07}$	6022,71
	22,55	100	30	$2,72\times10^{-03}$	$1,04\times10^{-06}$	2618,44
		200	30	$5,44\times10^{-03}$	$9,99\times10^{-07}$	5440,24
	24,46	100	30	$2,71\times10^{-03}$	$1,56\times10^{-06}$	1734,64
		200	30	$5,43\times10^{-03}$	$1,44\times10^{-06}$	3754,04
Stevia leaves	63,22	100	300	0,03	$2,37\times10^{-05}$	1281,52
		200	300	0,06	$2,31\times10^{-05}$	2606,08

2.1.5 Process energy balance

Corn grain treatment with laser beam set-up and 30 s illumination period was applied for energy consumption determination. The evaporated moisture content was measured and is given in Tab. 1 as the mean of three repetitions. Using the amount of evaporated water and knowing the amount of expanded energy of laser radiation, energy needed for water evaporation from these corn grains in the elementary layer was determined.

Table 2 Comparison of energy consumption during convectional and laser drying processes

Corn kernels moisture content (% w.b.)	Laser output power (mW)	Increase in energy consumption compared to average energy consumption of convectional dryers (times)	Energy savings compared to average energy consumption of convectional dryers (%)
13,48	100	3,50	-
	200	6,46	-
15,68	100	1,82	-
	200	3,41	-
17,72	100	1,17	-
	200	2,64	-
20,51	100	-	23,96
	200	1,43	-
22,55	100	-	37,66
	200	1,29	-
24,46	100	-	58,70
	200	-	10,62

Table 3 Duncan's multiple range test of significant difference (5%) between kernel groups treated with 100 mW and 200 mW output power laser beam

	Corn kernels moisture content (% w.b.)					
	13,48 %	15,68 %	17,72 %	20,51 %	22,55 %	24,46 %
	Consumed energy for evaporation (kJ/kg)					
Laser output power (mW)	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F
	<0,001	<0,001	<0,001	<0,001	<0,001	<0,001
100	14726,59^{b} ± 2507,92	7657,23^{d} ± 1570,35	4902,27^{ef} ± 479,24	3193,86^{efg} ± 531,97	2618,44^{fg} ± 706,99	1734,64^{g} ± 233,43
200	27127,94^{a} ± 4261,57	14326,44^{b} ± 1874,33	11083,37^{c} ± 482,94	6022,71^{de} ± 652,66	5440,24^{def} ± 669,13	3754,04^{efg} ± 171,82
	Combinations of factors					
Laser output power × moisture content	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F	Pr > F
	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Data are expressed as average value ± standard deviation (*n* = 3).

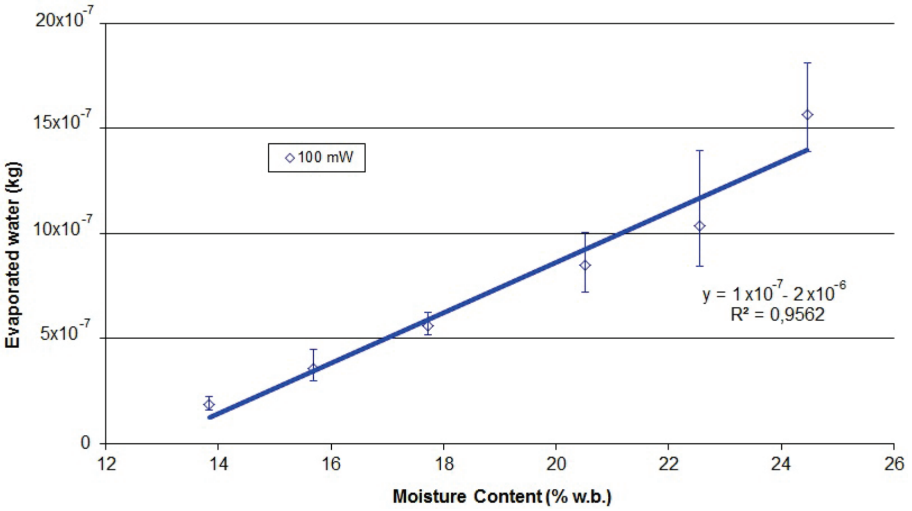

Figure 3 Effect of moisture content on evaporated water during 100 mW laser treatment

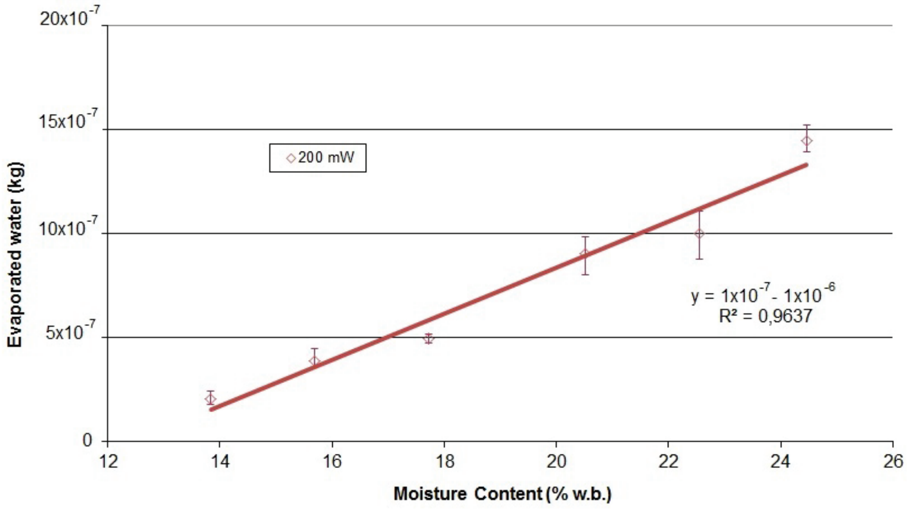

Figure 4 Effect of moisture content on evaporated water during 200 mW laser treatment

Knowing that typical energy consumption in existing convectional industrial dryers ranges from 3500 kJ to 4600 kJ for 1 kg of evaporated water, comparison of energy consumption was made between conventional and laser drying. The results are shown in Tab. 2.

The experiments with laser illumination were also performed with stevia leaves at the same levels of radiation intensity (10 kW/m^2 and 20 kW/m^2). Leaves were placed in single layer on the dryer platform after preparing and adjusting the dryers for the treatment. During the drying process, reduction in the weight of the samples was measured using a precision balance and was recorded. Illumination was carried out for 5 min.

3 Results

3.1 Laboratory measurements and comparisons

The evaporated water for elementary (thin) layer in the 30 second laser drying experiment of corn grains is shown in Fig. 3 and Fig 4.

According to a randomized block design (with three replicates), Duncan's multiple range test was performed to determine the significance of differences within the examined factors (moisture content and laser beam output power), using the commercial software SAS [23]. Values are presented as the mean ± SD of three replications in Tab. 3. *P*-values lower than 0,05 were considered statistically significant.

4 Discussion

It is well known that during convectional drying, drying rate depends on several variables, such as drying time, grain depth, temperature of the heated air, and airflow rate. Pliestić [24] measured energy consumption for corn grain drying in laboratory hot air dryer. The author indicates that the worst case condition of the hot air drying process can be induced by both smaller corn grains (5 %), lower air temperature (2 %), lower air velocity (12,5 %), thus contributing to 17,5 % of total possible error margin of the calculated data. For most convective dryers, the energy required for evaporation of moisture together with that lost in exit airstreams dominates the energy demand. Statistical data obtained from heat balances of convective dryers show that 20 to 60 % of the heat supplied to the dryer is used for moisture evaporation, 5 to 25 % for material heating, 15 to 40 % for heat losses with the exhaust air, 3 to 10 % for heat losses from dryer walls to the atmosphere, and 5 to 20 % for other losses [25].

The mechanism for drying with electromagnetic radiation is quite different from that of convectional drying. When electromagnetic waves strike a body, they may be absorbed, transmitted, or reflected. Absorptivity, reflectivity, and transmissivity are the key radiation properties and they may vary with wavelength and the type of grain. According to Fig. 5, moisture content of the material also affects the mentioned radiation properties.

For drying grain samples with higher moisture content, between 20 % and 30 %, typical energy consumption in convectional industrial dryers ranges from 2500 kJ to 3500 kJ for 1 kg of evaporated water [2, 3]. Therefore, according to the results from Tab. 2, potential for significant energy savings exists with our method and inside this humidity range. In our research, energy data calculations are referred to actual evaporated moisture content. According to Tab. 2, the least efficient portion of a laser drying, like in conventional drying system, is near the end of process, when two thirds of the time may be spent removing the last one third of the water. Results indicate that 100 mW laser drying processes have some promising aspects, such as 23,96 % to 58,70 % savings in samples with moisture content between 20,51% and 24,46%. Less energy savings (10,62 %) were observed during the 200 mW laser treatment also in samples with higher moisture contents (24,46 %).

The reason for this enhanced energy transfer between laser and corn grains compared to classical thermo dynamical hot air energy transfer may be contributed to the more direct energy exchange in laser drying set-up than in conventional hot air drying process.

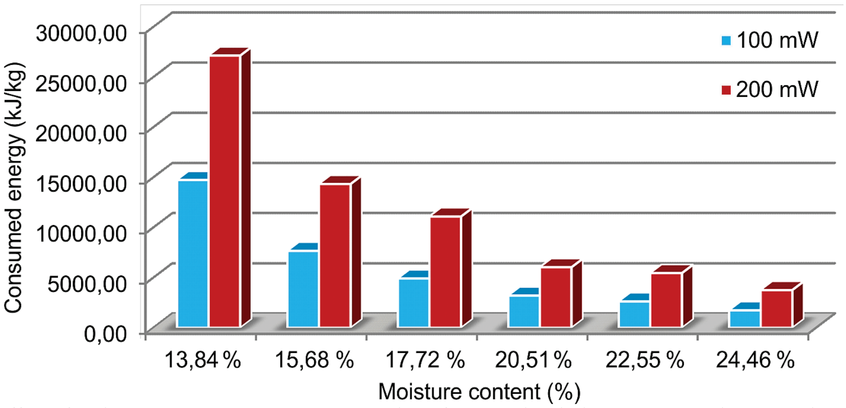

Figure 5 Effect of moisture content on energy consumption of corn grains during 100 mW and 200 mW laser treatment

Fig. 6 and Fig. 7 show the rate of moisture removal for laser drying of stevia leaves. As can be observed, moisture removal efficiency slightly increases with increasing illumination intensity. Also, laser illumination of stevia leaves showed higher removal efficiency of moisture than corn grains, probably due to cell and tissue structure of illuminated materials.

In addition to energy savings at higher levels of moisture, the efficiency of laser drying needs to be considered. By applying the laser illumination at the entrance to the dryer, the electromagnetic radiation forces moisture to the surface and immediately permits the conventional dryer to operate at its most efficient condition, at higher temperatures. This method also provides close control of the process, and in spite of the greater cost of energy, the overall increase in drying efficiency and throughout can bring about significant economic savings. By combining these drying methods properly, it is possible to draw on the benefits of each and maximize efficiency to keep the costs of drying low.

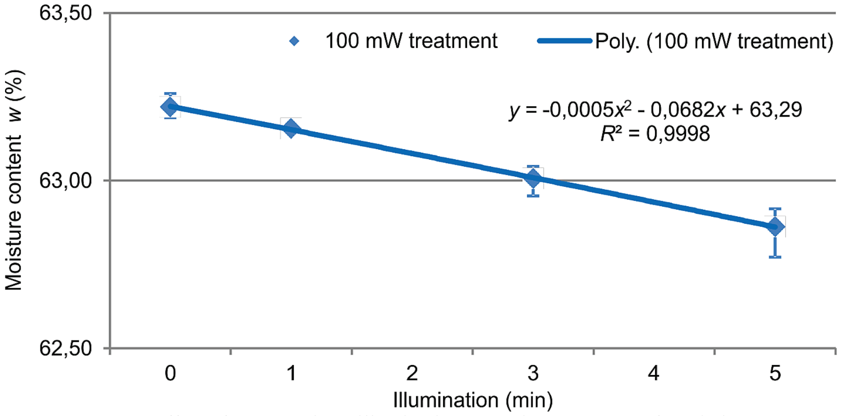

Figure 6 Effect of 100 mW laser illumination on moisture content of stevia leaves

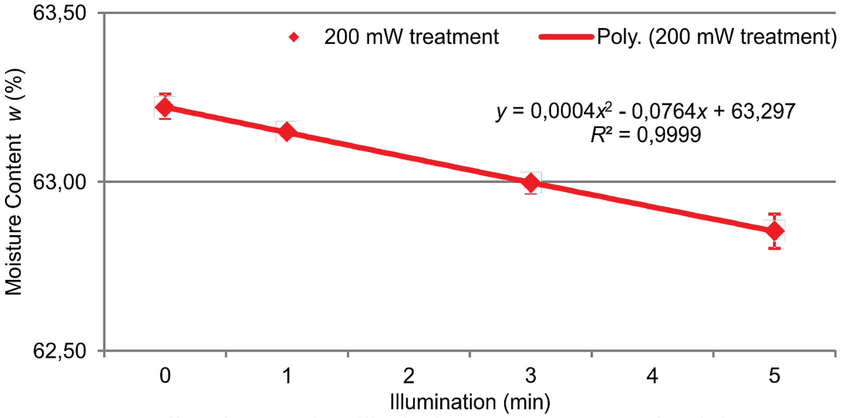

Figure 7 Effect of 200 mW laser illumination on moisture content of stevia leaves

Statistical analysis in Tab. 3 showed significant difference ($p < 0,05$) for all measuring points between kernel groups treated with 100 mW and 200 mW output power laser beams. The statistical analysis of the interaction between laser output power and moisture content is also outlined in Tab. 3. According to the results, a significant difference of the interaction was observed for all moisture levels of corn kernels.

5 Conclusion

The cost of electricity as well as fossil fuels clearly drives the choice of the system chosen. Also, efficiency of drying needs to be considered in the context of global warming and environmental protection. Energy consumption with the burning of fossil fuels leads to CO_2 emission. These indirect atmospheric effects of drying systems will have to be reduced by more efficient drying processes. At the same time, environmental considerations require that the emission of solvents be minimized and, as far as is practical, eliminated.

A type of phenomenon of directed energy transfer with enhanced drying effect on corn grain has been indicated while treating corn grains with 100 mW (655 nm) and 200 mW (660 nm) collimated laser beams. The energy savings increase compared to classical hot air drying both in laboratory conditions was between 23,96 and 58,70 % (100 mW laser) and 10,62 % (200 mW laser), depending on grain wet basis and decreasing with decrease of moisture content. The resultant process has exhibited stable drying behaviour under two different laser excitations.

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7 References

[1] Katić, Z. Grain drying – power balance and technology solutions. // Proceedings of the 1st International Congress of Technologists for Post-harvest Technology / Stubičke Toplice, 1985, pp. 4-55.

[2] Katić, Z. Drying and dryers in agriculture (Sušenje i sušare u poljoprivredi), 1st ed. Multigraf d.o.o., Zagreb, 1997.

[3] Meiering, A. G.; Daynard, T. B.; Brown, R.; Otten, L. Drier Performance and energy use in corn drying. // Canadian Agricultural Engineering. 19, 1(1977), pp 49-54.

[4] Cohen, J. S.; Yang, T. C. S. Progress in food dehydration. // Trends in Food Science and Technology, 6(1995), pp. 20-25.

[5] Mohammadi, A.; Rafiee, S.; Keyhani, A.; Emam-Djomeh, Z. Estimation of Thin layer drying Characteristics of Kiwifruit (cv. Hayward) with Use of Page's Model. // Journal of Agric. & Environmental Science. 3, 5(2008), pp. 802-805.

[6] Bruce, D. M. Exposed layer barley drying: three models fitted to new data up to 150 °C. // Journal of Agricultural Engineering Research. 32, 4(1985), pp. 337-348.

[7] Sokhansanj, S.; Singh, D.; Wasserman, J. D. Drying characteristics of several grains subjected to repetitive wetting and drying cycles. // Transactions of the ASAE. 27, 3(1984), pp. 903-906, 914.

[8] Misra, M. K.; Brooker, D. B. Thin layer drying and rewetting equations for shelled yellow corn. // Transactions of the ASAE, 23, 5(1980), pp. 1254-1260.

[9] Agrawal, Y. C.; Singh, R. D. Thin layer drying studies for short grain rice. // Transactions of the ASAE. 70, 1(1977), pp. 330-350.

[10] Overhults, D. G.; Ross, I. J.; White, G. M.; Hamilton, H. E. Drying soybeans with heated air. // Transactions of the ASAE, 16, 1(1973), pp. 112-113.

[11] Li, Y.; Morey, V.; Afinrud, M. Thin layer drying rates of oilseed sunflower. // Transactions of the ASAE. 30, 4(1987), pp. 1172-1175, 1180.

[12] O'Callaghan, J. R.; Menzies, D. J.; Bailey, P. H. Digital simulation of agricultural drier performance. // Journal of Agricultural Engineering Research. 16, 3(1971). pp. 223-244.

[13] ASABE Standards S448.1: Thin layer drying of agricultural crops. St. Joseph, Mich.: ASABE, 2006.

[14] Čikić, A.; Samardžić, I.; Stoić, A. A contribution to the development of moisture measuring of vacuum-dried hygroscopic materials. // Tehnički vjesnik - Technical Gazette. 20, 1(2013), pp. 137-145.

[15] Jablan, M.; Buljan, H.; Soljacic, M. Damping of plasmons in grapheme. // News&Views in Nature Photonics. 7, (2013), pp. 346-348.

[16] Nenadic, K.; Jovic, F.; Pliestic, S. An investigation of automatic treatment of seeds with low power laser beam. // Automatika. 49, 3-4(2008), pp. 127-134.

[17] Jovic, F.; Pliestic, S.; Kolak, I.; Jagnjic, Z.; Blazevic, D. Estimation of the laser beam scattering in food grain preprocessing. // Proceedings of the 17th Meeting on Mathematical Modelling of Materials Processing with Lasers: M4PL17. Luleå, Kaplan A.: Igls / Innsbruck, 2004.

[18] Milosavljevic, A; Petronic, S.; Kovacevic, A.; Kovacevic, Z.; Stamenic, Z. Laser shock peening of n-155 superalloy after longtime service. // Tehnički vjesnik - Technical Gazette. 20, 2(2013), pp. 323-327.

[19] Bammer, F.; Schumi, T.; Otto, A.; Schuöcker D. Laser assisted bending for efficient light-weight-production. // Tehnički vjesnik - Technical Gazette. 18, 4(2011), pp. 571-576.

[20] Galic, A.; Nenadic, K.; Pliestic, S.; Jovic, F. A nonlinear impact of low energy laser beam on corn kernel drying. // Third IFAC International Conference Agricontrol. 3, 1. / Kyoto, 2010.

[21] Jovic, F.; Nenadic, K.; Drezner, G.; Kovacevic, J.; Dvojkovic, K. Visible Wavelength Laser Beam Treatment of Wheat Grain. // Proceedings of the 19th Meeting on Mathematical Modelling of Materials Processing with Lasers: M4PL19. / Innsbruck, 2006.

[22] HRN ISO 6540:2002 Maize - Determination of moisture content (on milled grains and on whole grains) (ISO 6540:1980), 2002.

[23] SAS Statistical Analysis System. Version 9.1.2. Cary, N.C.: SAS Institute, Inc., 2004.

[24] Pliestic, S. Dependency of fluidization start on grain wet basis and air velocity during drying process in hybrid corn grain Bc 492 (Zavisnost početka fluidizacije kukuruznog zrna hibrida Bc 492 o vlazi zrna i brzini zraka tijekom sušenja). PhD thesis, University of Zagreb, Faculty of Agriculture, Zagreb, 1995.

[25] Danilov, O. L.; Leontchik, B. I. Energy Economic in Thermal Drying Energoatomizdat, Moscow, 1986

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