BARLEY GRAIN PRE-DRYING USING A LOW-ENERGY LASER BEAM

PREDSUŠENJE ZRNA JEČMA KORIŠĆENJEM NISKO ENERGETSKIH LASERSKIH ZRAKA

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ABSTRACT

A laboratory laser beam method for drying barley grains is presented and the corresponding energy transfer is analyzed. Barley grains were illuminated from one side during a period of 60 seconds with 100 mW 650 nm and 200 mW 650 nm collimated laser beams. The intensity of laser radiation within the illuminated area was 12.74 Wsm^{-2} for a 100 mW laser and 25.48 Wsm^{-2} for a 200 mW laser. Barley grain samples with moisture contents of 18 %, 20 % and 25 % were used for analysis. The results obtained show differences in the energy consumption between grains with different initial moisture contents. Compared to convective hot air drying, the energy savings of 51 % were achieved using a 100 mW laser on the grain samples with a moisture content of 25% under laboratory conditions. Moreover, the energy savings were found to depend on the grain wet basis and decrease with the decreasing moisture content.

Keywords: energy efficiency, pre-treatment, drying, laser power, barley grain.

REZIME

Ovaj rad analizira metodu sušenja zrna ječma laserskim zračenjem u laboratorijskim uvjetima i prijenos energije tijekom procesa. Elementarni (tanki) sloj zrna tretiran je laserskom svjetlošću. Zrna ječma osvijetljavana su s jedne strane tijekom 60 sekundi sa 100 mW laserom valne duljine 650 nm i 200 mW laserom valne duljine 650 nm. Intenzitetzračenja unutar osvijetljenog područja za laser od 100 mW iznosi 12.74 Wsm^{-2} a za laser od 200 mW 25.48 Wsm^{-2} . Za analizu su korišteni uzorci ječma s različitim početnim udjelima vlage od 18, 20 i 25%. Analizom dobivenih rezultata uočene su razlike u količini utrošene energije pri sušenju zrna s različitim početnim udjelom vlage. Uštede u potrošnji energije u iznosu od 51% ostvarene u laboratorijskim uvjetima u odnosu na klasični način sušenja zagrijanim zrakom zabilježene su kod sušenja 100 mW laserom kod uzoraka sa 25% vlage. Također, utvrđeno je da ušteda u potrošnji energije za sušenje ovisi o početnoj vlažnosti materijala i smanjuje se sa smanjenjem sadržaja vlage materijala. Dodatna prednost laserskih uređaja za tretiranje zrna očituje se u njihovoj mogućnosti jednostavne ugradnje u na trakaste i vibracijske transportere unutarnjeg transporta, njihova primjena nije štetna za okoliš, a ujedno smanjuju i potrebu za energijom u transportu radnog medija. Budući da je interakcija između lasera i tretiranog materijala složen proces, nužno je istražiti uskladihost između izlazne snage lasera, duljine tretmana i biološkog efekta procesa.

Ključne riječi: energetska učinkovitost, predtretman, sušenje, snaga lasera, ječam.

INTRODUCTION

Grain drying is the most important pre-processing treatment prior to storing grains for a longer period of time. It is noteworthy that drying as a process of grain preservation incurs high financial costs. The energy required for moisture evaporation, alongside that lost in exit airstreams, accounts for most of the energy requirements of a convective dryer. According to Danilov and Leontchik (1986) and Mujumdar (2014), only 20 to 60 % of the heat supplied to the dryer is used for moisture evaporation, whereas 5 to 25 % is used for material heating, 15 to 40 % for heat losses via the exhaust air, 3 to 10 % for heat losses from dryer walls to the atmosphere, and 5 to 20 % for other losses. Although convective grain drying with preheated air is expensive, it is still a dominant pre-processing treatment. According to Katić (1997), the share of grain drying costs can claim up to 25-30% of the total production costs. Nowadays, considerable efforts are expended to achieve energy consumption and cost reductions in drying procedures. One of such attempts is to improve the construction of hot air dryers using different construction and insulation materials, or the energy recirculation and recuperation. Another means to achieve energy consumption and cost reductions is the application of different methods for drying such as radio frequency, laser light, NIR, microwave and vacuum drying. According to Čikić et al. (2013), the vacuum system is the best solution for the removal of the vapour produced in processes where heat can be supplied by radiation or conduction. Starzycki et al. (2005) indicate that alternative energy sources such as low-power lasers could be a

feasible tool to perform the pre-drying process. Electromagnetic radiation drying is quite different from convectional drying. Electromagnetic waves can be absorbed, transmitted, or reflected by grains. However, electromagnetic radiation properties (absorptivity, reflectivity and transmissivity) can vary with wavelength, the type of grains and the moisture content of grains. During electromagnetic radiation drying, the energy is transferred directly to the material being heated, and thus is not expended by heating the air, oven walls or other equipment items as in conventional drying methods (Mujumdar, 2014). Therefore, this kind of drying is conducive to energy savings. According to Hernández et al. (2006), the laser output power greater than 1 mW has been found potentially destructive. It can permanently damage the human eye and affect the proper vision. Consequently, treatments with the laser output power greater than 1 mW requires compliance with the prescribed safety measures. Jović et al. (2006) also argue that lasers with greater power can permanently damage the grain even if the exposure period is very short. Same authors also state that, although a laser illuminates only one side of the grain, the surface layer of the grain can disperse the laser beams around the entire surface of the grain, thus reducing the treatment duration. Nenadić et al. (2008) report that different grain types do not disperse laser light in the same manner due to differences in the surface structure. In addition to moisture content removal, laser beams can also be successfully applied to the fungi removing process and to sprout stimulation (Jović et al. (2006), Nenadić et al. (2007) and Nenadić et al. (2008). The balance between the laser power and its biological effect on the materials treated require further in-

depth research. Therefore, the primary purpose of this study is to explore the energy efficiency of the laser application to barley grain drying.

MATERIAL AND METHOD

Barley grains of the cultivar 'Gazda' were manually cleaned from filth and other materials. Only whole, healthy and undamaged grains were considered for treatment. In order to prepare the samples with moisture contents of approximately 18 %, 20 % and 25 %, grains had to be conditioned. Distilled water was used to increase the grain moisture contents as follows:

$$M_V = M_U \frac{w_2 - w_1}{100 - w_2}$$

where

- M_V is the amount of distilled water in grams (ml),
- M_U is the mass of the sample in grams,
- w_1 is the initial moisture of the sample (%),
- w_2 is the expected moisture of the sample after adding distilled water (%).

Grain samples were conditioned in hermetically sealed glass containers kept at an air temperature of about +5 °C (± 1 °C) for 5 days and periodically shaken to homogenize the grains. Accordingly, barley grains were fixed at moisture contents of 18.12 %, 20.33 % and 25.25 %. The sample moisture contents were determined according to the HRN ISO 6540:2002 procedure using the 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 remained constant.

The laboratory laser set-up is shown in Figure 1.

Fig. 1 Laboratory set-up for the stationary laser beam treatment of grains

A laser beam source and a micro-objective are two main pieces of the treatment equipment. A total of two laser beam sources with output powers of 100 mW (model HLM1845) and 200 mW (model HLP18130) were used to expose barley grains to the laser beam energy. Both laser beam sources have the same output light wavelength of 650 nm, in the red visible part of the light spectrum. Different power outputs were used to determine the effect of power on the moisture removal process. The elementary (thin) layer of grains, containing from 272 to 350 grains, was placed in the illuminated area (100 mm in diameter under the laser source). The distance (LM) between the laser source and the micro-objective was 70 mm, whereas the distance (MK) between the micro-objective and the grain sample was 320 mm. The grain plate was placed on the laboratory analytical balance (Sartorius BP 221S, Göttingen, Germany) with a measurement accuracy class I scale interval of 0.1 mg. Grains were illuminated only from one side for 60 seconds. During the drying process, reductions in the mass of the samples were measured and recorded after the end of the treatment. During the drying process, the laboratory environment humidity was

between 77-80 % and atmosphere pressure approximated to 1012 hPa.

RESULTS AND DISCUSSION

Dinoev et al. (2004) found that physiological changes occurring in the treated plant material mostly depend on the laser radiation type, its wavelength and intensity. During these experiments, the illuminated area surface (100 mm in diameter) is calculated as follows:

$$A = r^2 \pi = 7.85 \times 10^{-4} \text{ m}^2$$

Therefore, the intensity of laser radiation within the illuminated area for a 100 mW laser can be calculated using the following equation:

$$\frac{E_{\text{laser}}}{\text{Illuminated area surface}} = \frac{0.1 \text{ Watt}}{7.85 \times 10^{-4}} \times T = 12.74 \frac{\text{W}}{\text{m}^2} \times T$$

where

T – treatment period (s)

The same equation can be applied for a 200 mW laser with an intensity of laser radiation of 25.48 Wsm⁻². The results obtained for the individual grain surface directly exposed to laser radiation are shown in Table 1.

Table 1. Illuminated individual grain area

Mois. content (% w.b.)	Illuminated surface of individual grain (mm ²)			
	Area	Min.	Max.	Range
18 %	23.17±1.60	20	26	6
20 %	23.84±1.79	20	27	7
25 %	25.22±1.51	22	28	6

*The results are presented as mean $\pm$ SD. (n=30)

On the basis of the illuminated surface of the individual grains (calculated using the graph paper) and the total number of grains in the elementary layer, the active surface of elementary layer and the intensity of laser radiation per active surface were calculated. The results obtained are shown in Table 2.

Table 2. Active surface of the elementary layer and the intensity of laser radiation per active surface

Moisture content (% w.b.)	Active surface (%)		Intensity of laser radiation per active surface (Wsm ⁻²)	
	100 mW laser	200 mW laser	100 mW laser	200 mW laser
18 %	93.61	97.47	11.93	24.83
20 %	98.07	95.51	12.49	24.33
25 %	95.68	96.17	12.19	24.50

*The results are presented as mean $\pm$ SD. (n=30)

The energy of individual photon can be calculated using the following equation:

$$E_{\text{individual photon}} = hv = \frac{hc}{\lambda} = 3.06 \times 10^{-18} \text{ J}$$

where

- h – Planck's constant (6.626×10^{-34} Js),
- ν – photon frequency for a semiconductor laser ($4.61538 \times 10^{15} \text{ s}^{-1}$),
- c – speed of light ($2.99 \times 10^8 \text{ ms}^{-1}$),
- λ – wavelength (650 nm)

The photon numbers from the individual laser sources were as follows:

$$n_{\text{photons 100mW}} = \frac{E_{\text{laser}}}{E_{\text{photon}}} = \frac{0.1}{3.06 \times 10^{-18}} = 3.27 \times 10^{16} \text{ photon s}^{-1}$$

$$n_{\text{photons } 100\text{mW}} = \frac{E_{\text{laser}}}{E_{\text{photon}}} = \frac{0.2}{3.06 \times 10^{-18}} = 6.54 \times 10^{16} \text{ photon s}^{-1}$$

The photons emitted from the source produced the following total force:

$$F_{100\text{mW}} = n_{100\text{mW}} \times P = 6.66 \times 10^{-11} \text{ N}$$

$$F_{200\text{mW}} = n_{200\text{mW}} \times P = 1.33 \times 10^{-10} \text{ N}$$

Table 3. Barley grain drying parameters

Laser	Moisture content (% w.b.)	Number of grains	Active surface (%)	Evaporated moisture (kg/elem. layer)	Energy for evaporation (kJ/kg)
100 mW	18 %	315.00 ± 8.43	93.61 ± 1.55	5.96×10 ⁻⁰⁶ ± 6.97×10 ⁻⁰⁷	4288.04 ± 402.02
	20 %	322.93 ± 10.54	98.07 ± 0.41	4.91×10 ⁻⁰⁶ ± 3.76×10 ⁻⁰⁷	4829.15 ± 364.90
	25 %	297.80 ± 11.23	95.68 ± 1.85	8.23×10 ⁻⁰⁶ ± 5.79×10 ⁻⁰⁷	2075.60 ± 150.25
200 mW	18 %	329.70 ± 11.04	97.47 ± 0.69	7.14×10 ⁻⁰⁶ ± 5.41×10 ⁻⁰⁷	7429.51 ± 577.17
	20 %	314.50 ± 9.41	95.51 ± 1.03	4.87×10 ⁻⁰⁶ ± 3.38×10 ⁻⁰⁷	9493.77 ± 657.61
	25 %	299.30 ± 11.55	96.17 ± 1.17	6.81×10 ⁻⁰⁶ ± 1.03×10 ⁻⁰⁶	5116.56 ± 684.53

*The results are presented as mean ± SD. (n=30)

On the basis of the laser output power and the treatment period, the total energy emitted by the laser light source during 60 seconds was calculated. Therefore, the energies emitted during the treatment period were 6 J and 12 J for a 100 mW laser and a 200 mW, respectively. The amounts of energy emitted by selected lasers are relatively small, thus the thermal effect of lasers is negligible. Therefore, it can be concluded that the laser impact on the plant material is based solely on biostimulation. The evaporated moisture content was measured to determine energy consumption, and the results obtained are shown in Tab. 3 as the means of 30 repetitions. On the basis of the amount of evaporated water and the amount of the energy of laser radiation expanded, the energy needed for water evaporation from the barley grains in the elementary layer was determined. On the bases of the average energy consumption of convective industrial dryers, i.e. 4,200 kJ per 1 kg of evaporated water (Katić 1997), a comparison of the energy consumption was made between convective and laser drying. The results obtained are shown in Tab. 4. According to the results obtained, at least the effective part of drying by laser radiation, as in the convective methods, is at the end of the drying process when two thirds of the time is spent to remove the last third of the water. The results of the 100 mW laser application are favourable, especially in grains with higher moisture content. The energy consumption decreased by 51 % in grains with a moisture content of 25 %. No

Table 4. Comparison of the energy consumption during convective and laser drying processes

Laser output power (mW)	Grain moisture content (% w.b.)	Changes in the energy consumption compared to the average energy consumption of convective dryers (times)
100 mW	18 %	+1.02
	20 %	+1.14
	25 %	-0.51
200 mW	18 %	+1.76
	20 %	+2.26
	25 %	+1.21

energy savings were achieved using a 200 mW laser. Moore et al., (2011) report that the reason for this is a better energy transfer in laser drying methods than in convective drying, probably due to the Förster - Dexter's energy transmission in dipole molecules in laser-stimulated organic materials. In addition to energy savings at higher levels of moisture, the efficiency of laser drying needs to be considered.

CONCLUSION

A type of directed energy transfer with a drying effect on barley grains was recorded especially at higher levels of the grain moisture content. In addition to energy savings, the efficiency of laser drying needs to be considered. The results obtained show a viable possibility of applying laser radiation to technological processes preceding convective drying. The laser radiation pre-treatment can stimulate the migration of moisture from the interior to the surface of the material, thus allowing for the greater efficiency of convective drying. Furthermore, this method of pre-treatment creates favourable conditions for the process automation, leading to an increase in the drying efficiency and financial savings.

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