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The change in weight and surface temperature of a pine cone (*Pinus sylvestris* L.) as a result of microwave irradiation

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Abstract. In this article, the author investigates the change of weight and temperature of pine cones in a microwave oven over the following range of microwave irradiation power (PMF): 800, 620, 440, 260 and 130 W.

Cones were divided into groups according to their weight and the author examined the influence of PMF on their water content and drying rate. The process is described with the help of mathematical equations and curves. The cones were irradiated in the microwave until all cones of the given group began to open the first scales. Small cones required longer exposure times to PMF than medium and large cones in order to cause scale opening. The most efficient of the five settings was a irradiation power of 620 W with an exposure time to microwaves for no longer than 20 seconds.

In the second part of the study, the author analyses the changes of temperature on the cone surface using a thermal imaging camera. The values of surface temperature depended on irradiation power and the duration of irradiation.

Keywords: seed extraction, microwave oven, water quantity, drying rate

1. Introduction

In order to obtain seeds from coniferous species, including Scots pine, Norway spruce, Common larch and Silver fir, seeds have to be extracted. This is a labour-intensive and time-consuming process. The methods to improve this process are investigated.

Many attempts have been undertaken to shorten the time of process of extraction. The temperature of drying was increased (Antosiewicz 1979), the pressure was decreased (Bogdanow 1966), the size of the cones was reduced mechanically by cutting off the base of the cone, the cones were segregated into groups of different sizes (small, medium, large), soaking of the cones in water was used during the gradual process of drying (Aniszewska 2012a, 2013). Despite many research efforts, the time of extraction wasn't significantly shortened. One of the reasons was the high sensitivity of seeds to external factors. Incorrectly selected parameters of extraction can cause damage to the seeds.

A significant improvement occurred in the field of seed science in Poland in recent years. Due to many investments, new objects were built and old objects of technical infrastructure were modernised, including kilns, stores, seed testing and seed control stations in which new technologies were introduced. The new objects have a large area and they are intended for processing large mass of reproductive material. In order to reduce the cost of extraction in such objects, the cones should be delivered regularly and in large number, which can be difficult to achieve in a non-seed year. In such years, the cost of extraction is usually high and can exceed even 15.00 PLN / kg of cones (without depreciation costs of the facilities) (Aniszewska, Zychowicz 2008).

In the 1960s, there was an idea of equipping each forest inspectorate in small seed huller, which was supposed to allow fast obtaining of seeds collected by cones' owners. As a result, only a small number of hullers were produced, because of the fact that they didn't meet the quality criteria. The weak element of the device was the control system of extraction process. It resulted from the lack of knowledge in this field and technical capabilities of the drying industry. Presently, thanks to the development of this section, the construction of devices of this kind is no longer a problem. An attempt to draw guidelines for

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the construction of new, small extraction devices used for maximisation of the number of obtained seeds seems to be right. An improved process of extraction could be used in devices in which extracted could be small portions of cones.

In order to decrease the initial humidity of the cones, and as a result to reduce the time of scales leaning from the axis, the use of electromagnetic rays (microwaves) in the first phase of one- or two-stage cones extraction was proposed. The first stage of the process will allow for a fast loss of the water from closed cones, which will lead to loss of the mass and the beginning of opening of the scales. The beginning of scales opening is considered to be the moment in which individual scales separate from each other with no visible leaning from their axis. This first move will have an influence to give better and more intensive leaning of the scales and exposure of seeds in the next phase of first stage of extraction, that is, cabinet kiln or cone extraction chamber.

However, in order to use electromagnetic irradiation universally, the recognition of the way in which microwaves influence the cones and seeds inside them is necessary. The time of irradiation exposure and its maximum power should be determined.

The aim of this article is the description of the mass of the cones, which were subjected to the microwave irradiation, using mathematical formula: changes in water content and the speed of drying rate of the cones until the moment of opening of the first scales and characteristics of the degree of heating up of the external surface of the material with the use of different power of electromagnetic rays.

In following article, the subject of seed quality was not examined. Only the change in mass, humidity and temperature of cones under the influence of irradiation were recorded. An assessment of the quality of obtained seeds in cones after use of microwave irradiation will be presented in another publication.

Microwaves are electromagnetic waves of frequency from 0.3 to 300 GHz and length of waves from 0.001 to 1 m. In microwave ovens, microwaves of frequency 2.45 GHz and length of waves around 120 mm are used. The described waves are reflected by metal and let through glass, paper and majority of plastics. During irradiation, the energy is transferred to the material as a result of which the temperature raises in the material. The increase of the temperature is a result of influence of microwaves on water molecules. Molecules are set in motion and they hit each other with great force. The molecules start to vibrate, taking over the energy of absorbed microwaves. The final effect of microwave activity is connected with humidity of the material. The more water is in the material, the more intensive is the microwave irradiation (PMF).

Over the years, there were attempts to use the reaction of electromagnetic field on living organisms. Electromagnetic waves can be used for improving the vitality of seeds, by killing the pathogens on the surface of the seed coat (Adair 2003), elimination of the hardness of seed coat, in order for them to germinate faster (Nelson 1985; Thuery, 1992; Warchalewski et al. 2007; Pietruszewski, Kania 2011; Cieśla et al. 2015), speeding of fruit drying process (e.g. kiwi) (Maskan 2001), vegetables (e.g. potatoes) (Khraisheh et al. 2004; Jakubowski 2008), rice (Pinkrová et al. 2003), destruction of parasitic fungi, pests in wood (Krajeński A, 1990a,b, 2001). Microwaves were used for soil disinfestations, instead of herbicides (Thuery 1992) or inhibition of seed germination on sow areas (Velázquez-Martí et al. 2006). A device for emission of microwave irradiation to soil was constructed. It is presently used in forest nurseries (Słowiński 2013) and in greenhouses.

Ballad and others (1976) also stated adverse impact of microwaves on seeds. Dried seeds had lower laboratory capacity of germination than those that were dried in traditional method of convection. According to Ballad and others (1976), the degree of reduction of germination capacity depended on the level of water content in the seeds. The authors stated that when the level of water was high, the damage of seeds appeared.

Opinions on the influence of the electromagnetic waves are divided and they depend on many factors (e.g. frequency or length of the waves, humidity, construction and structure of the material, etc.). On the basis of available literature, it cannot be stated explicitly whether short-term impact of irradiation on living organisms, including cones, is positive or negative.

2. Material and methods

For the research, Scots pine cones from economic seed stands (ESS) were used. Cones were collected in January 2015 and kept in kiln in Ruciane Nida on the area of Maskulińskie Forest Inspectorate (Regional Directorate of State Forest in Olsztyn). Closed cones were transferred to the laboratory of Department of Agricultural and Forest Machinery, where they were divided into five even parts. Each part consisted of 45 pieces of cones (including 15 small, 15 medium and 15 large cones). Small cones weighed up to 6.0 g, medium between 6.01 and 9.0 g and large over 9.01 g.

Single cones of different weights were, in sequence, subjected to PMF in laboratory's microwave oven SHARP R-200. Five ranges of power were used: 130, 250, 440, 620 and 800 W. The power of microwave oven was changed with the use of knob of the adjuster in the housing of the oven. Cones were subjected to electromagnetic rays until beginning of leaning of the scales in each cone was observed.

Before starting the research in microwave oven, the cones were weighed and their external parameters were measured (length and thickness). Mass measurement was made with the use of moisture balance WPS 210S, with an accuracy of 0.001 g. The measurement of grandiosity parameters was made with the use of slide caliper with an accuracy of 0.01 mm.

During research, the change in mass of a single cone was registered, with accuracy to 0.001 g, initially every 5 s, and later every 10 or 20 s depending upon the used power.

On the basis of measurement of the mass of single cones, the change in mass during the time of exposure to irradiation was calculated.

After finishing the research, the cones were dried in temperature 105 ± 1°C for 24 h in order to determine the dry mass. It allowed to describe changes in water content and to establish the drying rate during microwave irradiation exposure.

The change in mass was the difference between two following measured masses, whereas water content was calculated as a difference of cone mass measured after defined time of microwave irradiation and its dry mass. Acquaintance of water mass in the cones and cone's try mass allowed to calculate the absolute humidity in % according to the formula:

$$W = \frac{m_p - m_s}{m_s} \cdot 100\% \qquad (1)$$

where
m_p – is the initial mass of the cone and
m_s – the mass of a dry cone.

For description of changes in water content in cones, exponential equation corresponding to the second period of drying solids (Pabis 1982) was used:

$$u = (u_0 - u_k) \cdot e^{(-b \cdot \tau)} + u_k \qquad (2)$$

where:
u_0 – is the initial water content in the cone,
u_k – the final water content in the cone,
e – the base of the natural logarithm,
τ – the time,
b – the coefficient of cone susceptibility to change in water content.

Initial water content can be regulated by subjecting cones to preliminary drying. The final value of water content depends however on drying factor. Coefficient *b* was set for each cone on the base of actual course of changes in water content (Aniszewska 2012b). It is a parameter that characterises the cone's susceptibility to change in water content in the defined conditions.

Drying rate was calculated as a derivative of time and current water content (u) according to the formula:

$$\frac{du}{d\tau} = -b \cdot (u_0 - u_k) \cdot e^{(-b \cdot \tau)} \qquad (3)$$

A stage of microwave irradiation of cones was described with the use of exponential equation of water content and drying rate.

During this process, temperature and air humidity was registered with the use of Hygro–Palm gauge.

During research, pictures of single cones were taken with the use of thermal imaging camera VIGOcam V50. With the use of this camera, every 5, 10 or 20 s, the change of cone's surface external temperature until the moment of scale leaning from the axis was registered. During picture-taking, closed cones were lying on the edge of the plate of microwave oven.

Pictures were used for analysis of temperature change in following stages of microwave irradiation in dependence on the power of microwave oven. Therma program was used for image processing. The accuracy of temperature registration was 0.1°C.

Program Statistica 10 was used for statistical analysis of the results and also tests for small count of samples (Bruchwald 1997).

3. Results and discussion

3.1. Characteristics of the examined cones

For the research, 225 cones (75 small, 75 medium and 75 large cones) were collected. In the set, the smallest cone had an initial mass of 3.586 g, and the biggest-18.041 g. The average length of the cones was 45.38 mm (31.00 to 65.00 mm), and thickness 22.00 mm (16.40 to 30.2 mm).

According to other researchers (Sokołowski 1931; Staszkiewicz 1968; Białobok 1993), the cones of Scots pine from Europe have a length between 19 and 70 mm, and thickness between 12 and 35 mm. Therefore, the examined cones can be found in the range given for both grandiosity parameters.

The analysis showed a significant dependence between cone's length (*h*) and its thickness (*d*) ($R = 0.9162$). The increase of cone's thickness by 1 mm causes the increase of its length by around 2.15 mm. According to Staszkiewicz (1968), this increment is smaller and amounts to 1.70 mm.

The relationship between cone's initial mass (m_p), length (*h*) and thickness (*d*) was obtained. They are described by formulas (4) and (5).

$$h = 2.1935\, m_p + 27.365 \qquad (4)$$

$$d = 0.9475\, m_p + 14.214 \qquad (5)$$

The increase in cone's initial mass by 1 g is correlated with the increase of cone's length by around 2.2 mm ($R = 0.9363$), and its thickness by almost 1 mm ($R = 0.9469$).

3.2. Change of mass, water content and drying rate

The values of mass change of all cones from group: small, medium and large in each of five parts were averaged. The average change of mass of cones subjected to microwave irradiation of each power was showed on graphs (Fig. 1 a-e). For three groups of cones, varying in mass, trend lines were set and they were described with linear equations (6). Values of the coefficients *a* and *c* for those equations were given in Table 1.

$$m(\tau) = a\tau + c \qquad (6)$$

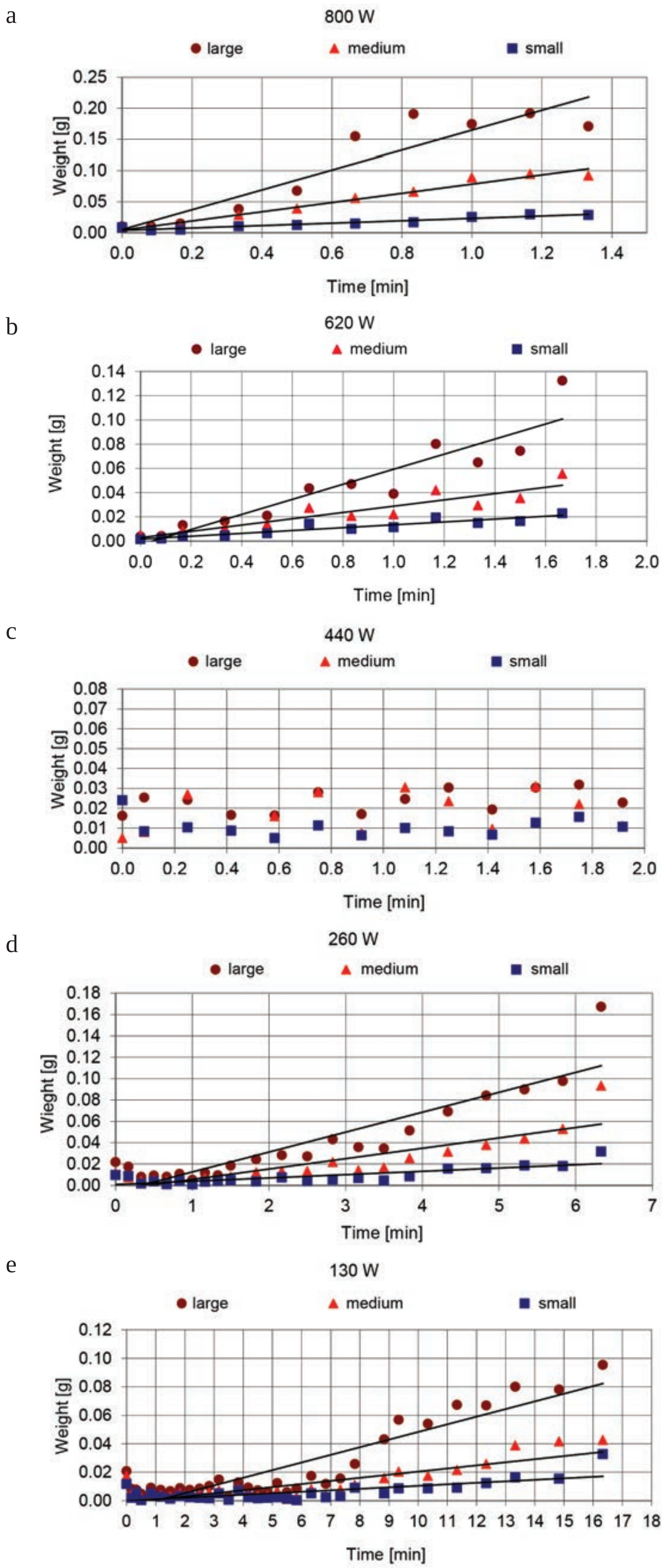


Figure 1. Weight change of small, medium and large cones under the influence of radiation-microwave with different power: a – 800 W, b – 620 W, c – 440 W, d – 260 W, e – 130 W

Table 1. The coefficients of linear equations (*a* – way, *c* – constant) describing the change in the weight of the cone under the influence of microwave radiation

Power [W]	Size cones	Coefficient *a*	Coefficient *c*	Coefficient *R*
800	large	0.1598	0.0051	0.9286
	medium	0.0743	0.0039	0.9857
	small	0.0193	0.0037	0.9613
620	large	0.0622	-0.0029	0.9294
	medium	0.0258	0.0030	0.9260
	small	0.0117	0.0017	0.9381
260	large	0.0187	-0.0062	0.9073
	medium	0.0097	-0.0042	0.8769
	small	0.0031	0.0007	0.8069
130	large	0.0054	-0.0053	0.9018
	medium	0.0022	-0.0013	0.8395
	small	0.001	0.00002	0.7235

Coefficients for equations for cones subjected to microwave irradiation of 440 W power were not given in Table 1, due to insufficient statistically value of correlation coefficient for trend line, described by equation of the first degree.

In equation (6), coefficient *c* is a constant and determines the point in which regression line meets the *y*-axis. For five equations, this coefficient has a negative value, and for the rest of them it has a positive value. Parameter *a* is a directional coefficient describing the gradient of the regression line inclination towards *x*-axis. The higher the value, the bigger the angle between *x*-axis and the regression line. The biggest inclination angle was observed in case of big cones and the power on the level of 800 W.

The time the cones spent in a microwave oven at the power of 800 W was for 1.5 min (0.225 s), at the power 660 W for 1.8 min (0.030 h), at 440 W for 4.8 min (0.080 h), 260 W for 7.2 min (0.120 h) and at 130 W for 18 min (0.300 h). The curves of drying, showed on Figure 2, indicate that irradiation intensity has a large influence on time of drying. Increasing of power from 130 to 800 W results in the reduction of drying time on average by 16.5 min (0.275 h).

The loss in mass is connected with the power of microwave oven. In time, it is also connected with the influence of electromagnetic rays on cones. At a power of 800 W, the greatest loss in mass was observed in case of large cones. During 1.5 min, the loss was over 1 g, which constitutes 8% of mass loss. On the other hand, at 130 W of power, a similar loss in mass was achieved after 18 minutes. In Table 2, the values of mass loss, in grams and percentages, under the influence of microwave irradiation are given.

Average loss in mass expressed as a percentage for all large cones amounted to 8.4%, for medium cones, it was 6.9% and for small cones, it was 5.9%.

On the other hand, humidity after the microwave irradiation amounted, respectively, to 16.2%, 17.7% and 18.3%.

In Table 2, values of mean humidity corresponding to the beginning of scale opening is given. They were calculated for three sizes of cones and for four power values of microwave irradiation (800, 440, 260 and 130 W). In Table 2, there is no data for 620 W power.

Examining of cones from the moment when scales started opening showed that regardless of the used power, initial humidity for scale opening was in the range from 18.3 to 24%. It was noticed that the higher initial humidity of the cones was the higher was humidity of the first moment the scale opened. The difference between the initial value and value of the beginning of the scale opening for all examined big cones was smaller than for the small ones. It results from the fact that small cones require evaporating more water in order to open its scales than big cones.

A detailed comparative analysis of values of the dependence of the beginning of scale opening on used power showed that cones subjected to microwave irradiation at 800 W power had the highest humidity at scale opening of 22.5%, and at 130 W the lowest, at around 20%. The difference between those values amounted on average, for large cones, to 1.7%, for medium cones to 2.7%, and for small cones to 3.3% wherein the difference in initial humidity between them amounted, respectively, to 2.3%, 0.2% and 1.1%.

The change in water content in time for five powers of microwave irradiation during cones drying is showed in Figure

Table 2. The mean values of weight loss and humidity for five radiation output and three sizes of cones

Power [W]	Time [h]	Size cones	Weight loss [g]	Weight loss weight dry [%]	Initial humidity [%]	Initial humidity open [%]	Humidity after the end of radiation [%]
800	0.025	large	1.020	8.33	25.66	22.40	17.33
		medium	0.491	5.78	23.80	22.60	18.02
		small	0.155	4.72	25.41	22.30	20.69
620	0.030	large	0.541	5.35	24.45	n/a	19.10
		medium	0.275	4.41	24.05	n/a	19.64
		small	0.129	3.26	21.91	n/a	18.65
440	0.080	large	0.836	10.42	25.50	21.90	15.08
		medium	0.624	11.01	26.89	21.60	15.88
		small	0.411	10.14	24.75	20.50	14.61
260	0.120	large	0.872	9.45	24.21	21.00	14.76
		medium	0.433	7.07	24.32	21.70	17.25
		small	0.182	5.46	24.89	20.90	19.43
130	0.300	large	0.790	8.46	23.42	20.70	14.96
		medium	0.348	6.04	23.64	19.90	17.60
		small	0.188	5.95	24.28	19.00	18.33

2(a–c). The water content decreased depending upon the microwave power. The fastest the water content decreased at the highest microwave power and the slowest decrease was seen at the lowest power. Cones drying in microwave oven runs much faster in comparison to drying in the convection dryer. It is connected with the temperature of drying. Electromagnetic waves, which influencing the material (cones), cause material's heating to over 100°C, while during traditional peeling to 60°C (Aniszewska, 2013).

The loss of water from cones from initial humidity to observed beginning of scales opening amounts on an average to over 3%. The time of exposure to electromagnetic rays for individual powers is variable and is up to 0.3 h, the shortest for 800 W power and the longest for 130 W power (Table 2). With convection drying in laboratory conditions (Aniszewska 2004, 2012a), the beginning of scale opening occurs after 3–4 h, whereas cones' humidity decreased at the time on average by 4–5%. At the same time, when comparing value of water loss from cones subjected to electromagnetic waves and their influence on convection drying in production conditions, it turns out that the beginning of cones opening in production conditions occurred after 16 h (peeling time depends on cones' humidity and parameters of drying air). Rukini (1997) performed a comparison of drying process in a traditional way (in convection dryer) and using microwave irradiation on the cones of Monterey pine (*Pinus radiata* D. Don). Rukini (1997) stated that it is best to peel cones in the kiln dryer at a temperature up to 60°C and in microwave oven for 30 s. In case of the second method of peeling, in order to obtain seeds of good quality, the cones should be soaked in warm water before placing them in the microwave oven.

In Table 3, the parameters of the model of water content change (2) and the drying rate (3) used for large, medium and small cones and five microwave powers are presented.

For the highest power, coefficient *b* amounted aver 30, and for the lowest over 4.5 (Table 3).

The graphs depicting the cones drying rate and its dependence on microwave irradiation time are shown in Figure 4.

It was observed that the drying rate and its changes are the bigger, the larger the cones are and the bigger irradiation power is. It can be noticed that drying rate changes in a way similar to linear dependence.

3.3. The change in cone's surface temperature

The change in temperature of single cone's surface during microwave irradiation was described on the base of pictures registered by thermal imaging camera. In Table 4 the time of irradiation and minimum and maximum temperature for each power of irradiation is presented.

a

b

c

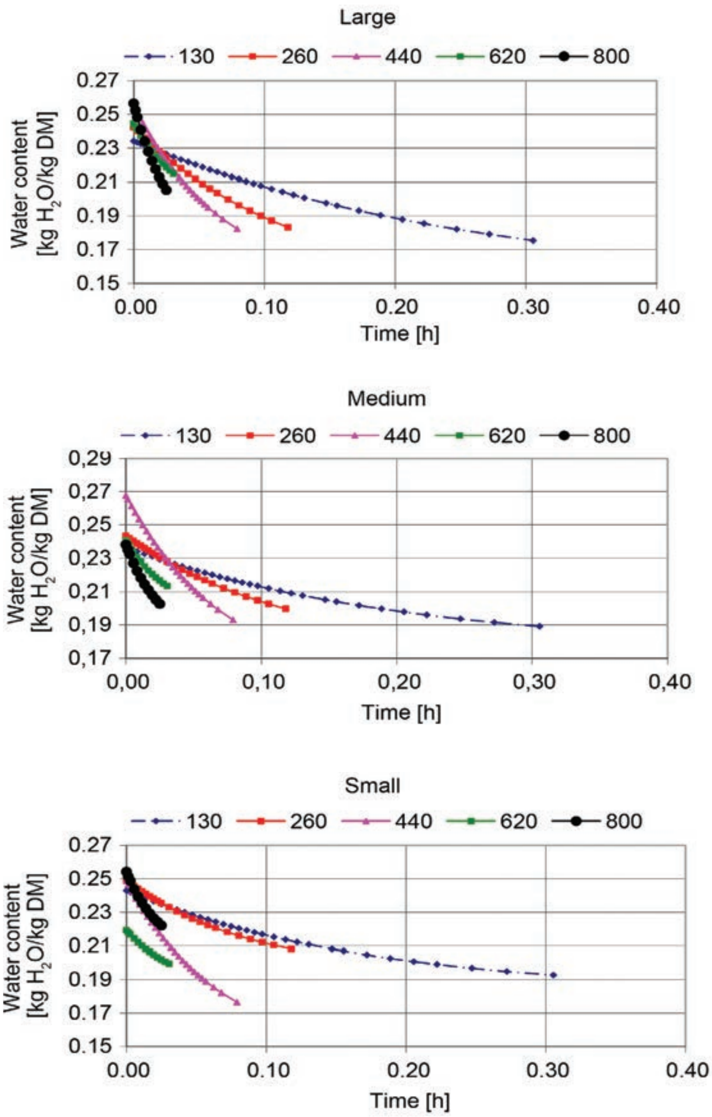


Figure 2. Change of water content in the cones: a – large, b – c medium – small under the influence of microwave radiation power: 800, 620, 440, 260 and 130

Air temperature inside the microwave oven during following attempts amounted to around 24°C, whereas the temperature of the room was around 22°C and air humidity was 50%.

Initially, the temperature of external layers of scales of a closed cone was read from pictures taken by thermal imaging camera and amounted to around 16°C. On the basis of the pictures, it was stated that the temperature of the inside of the cone, in the middle of its length, amounted on an average to 7°C (the cones were kept in the cooler before the examination). As a result of electromagnetic waves influence, the temperature on the surface of the cones increased intensively to 100°C. A single cone reached the temperature close to 100°C after only 5 s of irradiation at 800 W, whereas after 20 s at 620 W, after 25 s at 440 W and 260 W, and after 150 s at 130 W. In following stages, the temperature rose to 120°C. The only exceptions were cones subjected to irradiation at a power of 130 W. In this case, maximum temperature of cone's surface in the examined time was 100°C. This maximum temperature of the external surface was registered in the half of the cone's length (Table 4).

The time taken (in seconds) to reach 100% area of the cone at the temperature of 100°C is shown in Fig. 5. The area kept increasing with temperature.

In Figure 6, the values of maximum temperature reached after PMF irradiation (in seconds) on the surface of single cones depends upon the used power. It can be noticed that at the level from 130 to 620 W, the temperature raised and dropped, in turns, before it reached 100°C. It

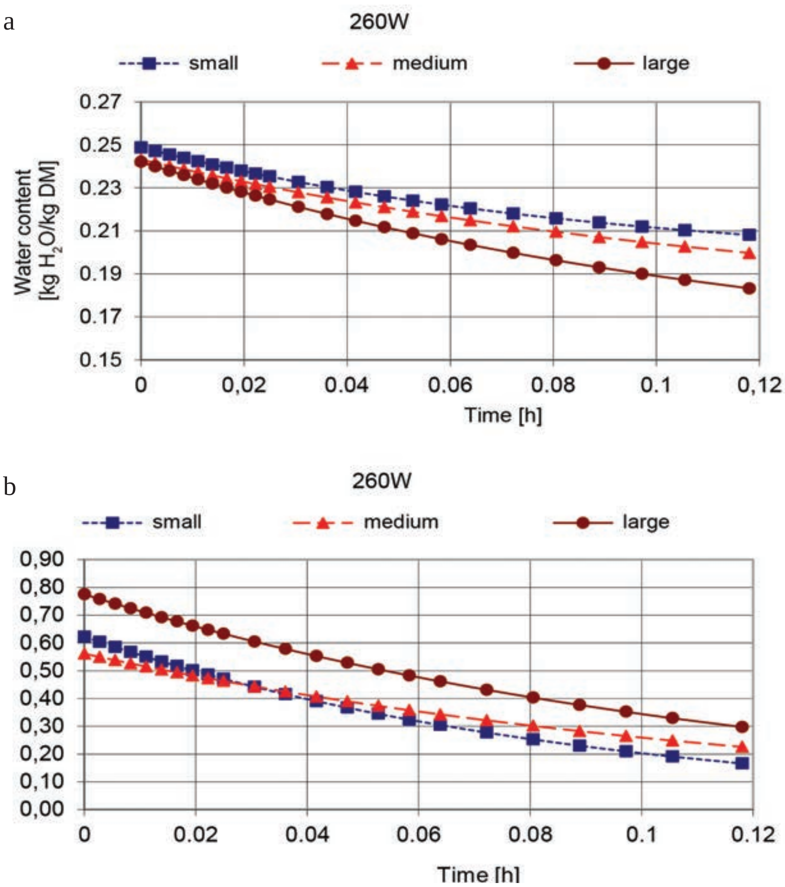
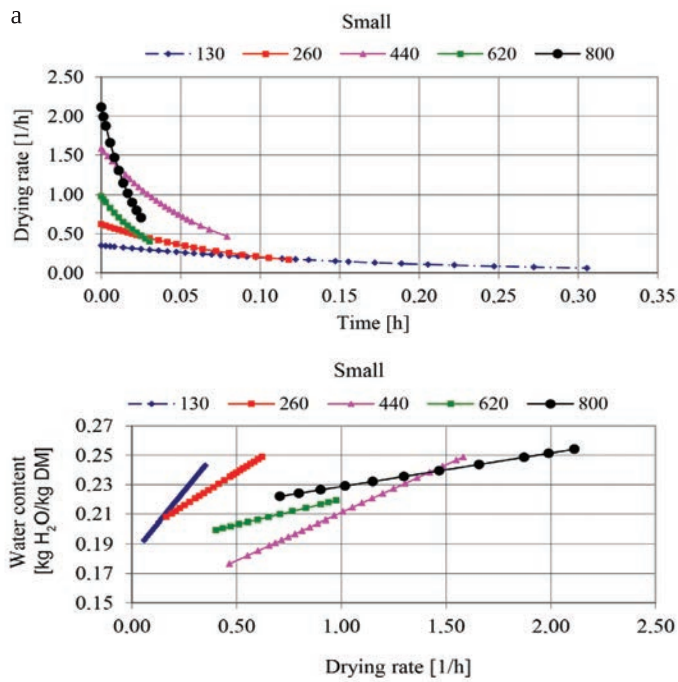


Figure 3. The changes in cones of small, medium and large size under the influence of microwave radiation with a power of 260 W, in terms of: a – water content, b – drying rate

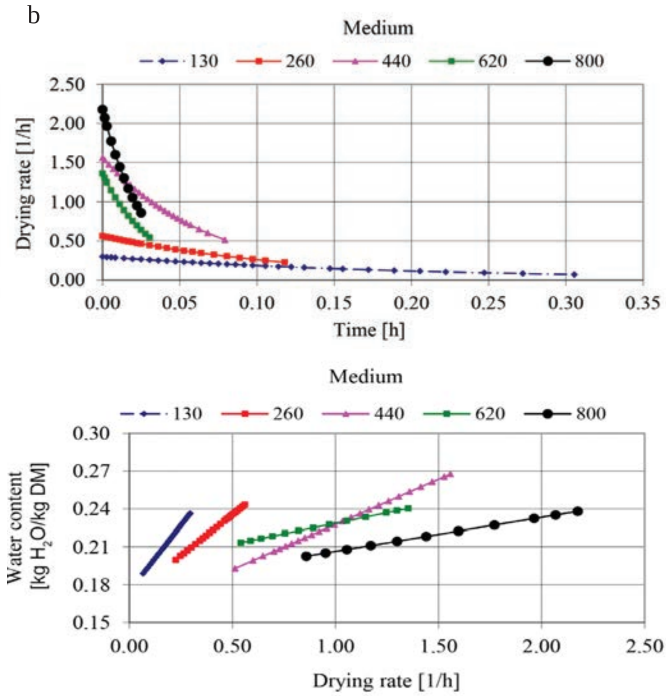
Table 3. The model parameters changes in water content and the drying rate when subjected to microwave irradiation of large size, medium and small cones

Power [W]	Size cones	Initial water [kg H_2O/kg DM] u_o	Final water [kg H_2O/kg DM] u_k	Coefficient b
800	large	0.2565	0.1723	37.464
	medium	0.2380	0.1796	37.222
	small	0.2540	0.2059	43.846
620	large	0.2445	0.1899	25.920
	medium	0.2404	0.1950	30.006
	small	0.2191	0.1856	29.113
440	large	0.2547	0.1495	14.736
	medium	0.2675	0.1565	14.026
	small	0.2487	0.1463	4.055
260	large	0.2421	0.1466	8.0121
	medium	0.2432	0.1705	7.722
	small	0.2488	0.1933	11.202
130	large	0.2341	0.1485	3.785
	medium	0.2364	0.1749	5.768
	small	0.2428	0.1822	5.784

a



b



c

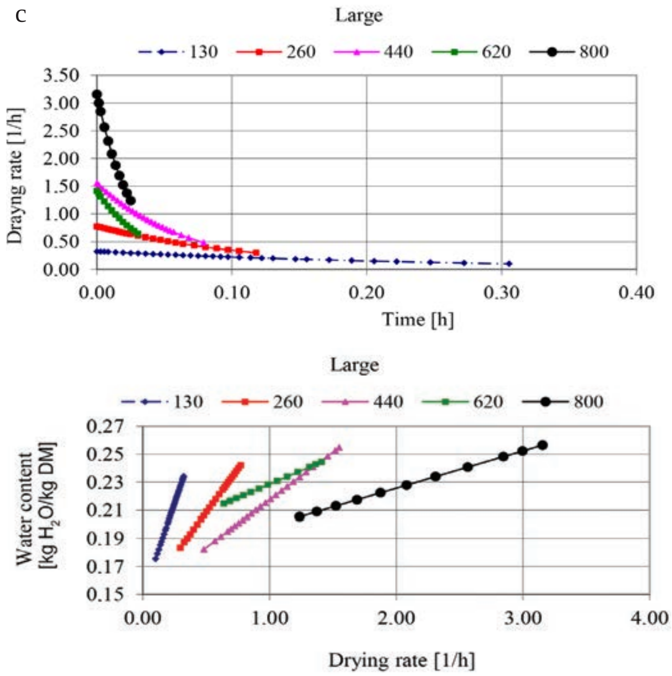


Figure 4. The drying rate of cones: a – small, b – medium, c – large under the influence of microwave power of 800, 620, 440, 260 and 130 W depending on the time and the water content

was caused by magnetron activity that transmitted electromagnetic waves, which depends upon power set in the microwave oven. The magnetron in the microwave is characterised by the fact that there is no possibility of controlling the quantity of microwaves transmitted by electrodes. So that is it possible to control the heating timeif voltage input to the magnetron is controlled. At the lowest power consumption, the lamp operates at full power, however, for a five-time period, and then a pause of several dozen seconds appears. As power increases, the heating time extends and the pause time shortens. It is showed in Picture 5.

Table 4. Mean values of the minimum and maximum temperatures of cones during heating at a power of 800, 620, 440, 260 and 130 W

Power [W]	Number	Time [s]	The surface temperature of cones [°C]	
			minimum	maximum
800	1	0	6.4	16.0
	2	5	52.0	94.0
	3	5	69.0	109.0
	4	5	79.0	119.0
620	1	0	7.0	16.7
	2	5	42.0	64.1
	3	5	40.0	54.5
	4	10	60.0	95.0
	5	10	76.0	120.0
440	1	0	9.0	14.0
	2	5	45.0	74.2
	3	5	42.0	66.3
	4	5	50.0	68.6
	5	10	71.0	97.1
	6	5	75.0	113.4
	7	5	68.0	99.8
260	1	0	18.0	12.7
	2	5	19.5	13.4
	3	5	19.0	14.2
	4	5	20.3	14.7
	5	10	70.0	105.8
	6	10	55.5	84.9
	7	10	48.4	76.6
	8	10	76.0	120.0
130	1	0	23.8	15.6
	2	5	23.3	17.2
	3	5	22.7	18.1
	4	5	22.3	18.8
	5	5	25.3	19.9
	6	10	51.0	80.5
	7	10	45.0	73.2
	8	10	44.0	69.3
	9	10	52.0	86.7
	10	10	47.9	75.6
	11	10	51.0	79.3
	12	20	45.3	70.6
	13	20	60.7	89.1

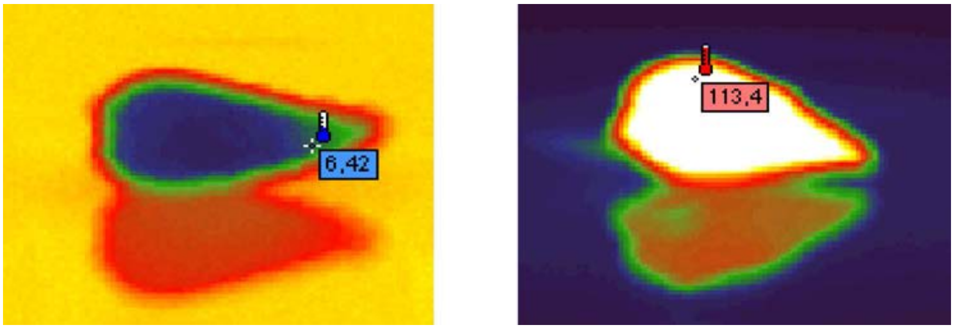


Figure 5. Example of picture cones heated by electromagnetic radiation 620 a – before, b – after 20 s

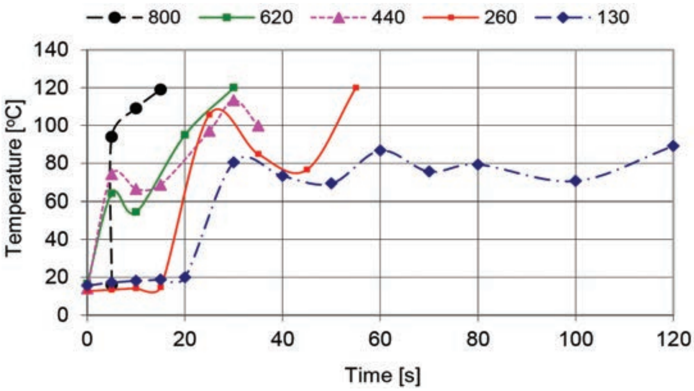


Figure 6. Changes of the maximum surface temperature of cones under the influence of microwave radiation

4. Summary and conclusions

The conducted research showed, that the increase in microwave irradiation allows for shortening of the time of water evaporation from the cones and their heating, which results in the acceleration of the moment when first scales open. At 800 W power, it was 1.5 min, at 130 W it was 18 min, whereas the loss in mass in both cases amounted around 3–4% (at the beginning of scale opening). The use of proposed initial stage of microwave irradiation in traditional process of drying can significantly shorten the peeling time. The advantage of this modernised peeling method is the short time in which the effect of first scale opening can be achieved. But in order to use this method, adequate power of microwave oven and the time of cones' exposure to irradiation should be selected, so that it does not influence negatively on seed quality.

1. The best option among examined ones is the irradiation power at 620 W and time of influence of microwave oven no longer than 20–30 seconds, which is confirmed by Rukoni's (1997) research.

2. For description of water content change in cones and drying rate under influence of irradiation, an exponential equation corresponding to second period of drying solids can be used.

3. It was stated that small cones need more time for water evaporation and the beginning of scale opening than medium and large ones. Therefore in order to use this method, cones should be segregated first.

4. The use of thermal imaging camera in the research allows for an assessment of the degree of heating of the cone's surface. At the power of 800 W, the heating of a single cone to 100°C appears after 5–10 s, and at 130 W after 120 s.

5. Research over evaluation of change in the temperature of the inside of the cone under influence of microwave irradiation should be conducted. Also attempts of PMF on a larger number of cones should be conducted in order to check how the temperature is distributed on the surface and inside of the cone after seconds of irradiation of the process.

Conflict of interest

The authors declare lack of potential conflicts.

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