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Comparison of thermal and thermomechanical methods of seed extraction from larch cones based on two case studies

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Abstract. The paper analyzes two seed extraction methods used by Polish silvicultural seed extractories. The analysis involves cone batches as well as individual cones processed in extraction cabinets. During thermal extraction, the cones were dried (10 h), moistened with water (10 min), and dried again (10 h). During thermomechanical extraction, the cones were dried for a much longer time (40 h), and then crushed in a mechanical unit (20 min). The two examined cases of seed extraction were compared in terms of the size, weight, and moisture content of the cones involved, the steps in the extraction process, as well as the quantity and quality of the obtained seeds. Each of the extractories made use of cones of a different provenance, which differed significantly from each other. In order to compare the different seed extraction methods, the same batch of cones collected from one geographic locality should be used. The results of a process analysis show that the thermal method was superior in terms of energy efficiency and duration. The seeds extracted using the two methods were of the highest quality (class I), which indicates that in both cases the extraction process was conducted appropriately and did not cause the quality of the seeds to deteriorate.

Keywords: scale kinematics, coniferous cones, seed extraction, quality assessment

INTRODUCTION

The European Larch (*Larix decidua* Mill.) is one of the six main tree species in Poland (Kantorowicz, 2000) and the dominant species in the Alps (Praeg and Illmer, 2020). Together with the pine, it occupies 70% of the area of Polish forests (State Forests, 2019). It is a native species (Jansen and Geburek, 2016) with two varieties: the Sudeten larch [var. *sudetica* (Cies.) Domin.] (Firsov *et al.*, 2016; Dostálek *et al.*, 2018; Semerikov *et al.*, 1999) and the Polish larch [*L. decidua* subsp. *polonica* (Racib.) Domin.] (Zawadzka, 2008; Jansen and Geburek, 2016). The most widespread among the foreign larch species is the Japanese larch (*L. kaempferi* Sarg.), which is native to the Japanese islands (Scheepers *et al.*, 2000).

200 to 500 kg of cones can be harvested from 1 ha of forest in Poland on average, which translates into 17.5-28.0 kg of seeds (Chałupka *et al.*, 2011; Fonder *et al.*, 2007). In the cones of Western larch (*Larix occidentalis* Nutt.) found in British Columbia, Canada, it was shown that the number of filled seeds produced is generally low, this is presumably due to a lack of pollination (Stoehr, 2000). According to the Department of Silviculture of the State Forests National Forest Holding (ZHL PGL LP, 2021) an average of approx. 10 000 kg of larch cones were harvested annually in the years 2010-2020. The most abundant harvests occurred in the years 2017 and 2020 (19 293 and 13 599 kg, respectively) and the least abundant occurred in the years 2011 and 2013 (2 676 and 5 944 kg, respectively).

The annual demand for the seeds of a given species is determined by the remaining stocks of the seeds from previous years. The plan for 2011-2035 is to maintain larch

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seed stocks at 1 000 kg (Chałupka *et al.*, 2011). The average total stocks of larch seeds in Poland in 2010-2020 were 967 kg (ZHL PGL LP, 2021), with the highest level recorded in 2010 (1 864 kg), and the lowest in 2015 (517 kg). The most desirable type of seeds are those with a quality standard of class I, which are characterized by a high degree of viability and the absence of microdefects, therefore they are suitable for long-term storage (up to 10 years) (Aniszewska, 2008; Załęski, 2002).

The process of seed extraction from larch cones takes longer than that for other cones of forest conifers (Aniszewska, 2008) due to their specific structure (Tulska *et al.*, 2021; Tyszkiewicz, 1951; Song *et al.*, 2015), it involves the seeds being ejected gradually in several kinematic cycles of scale opening and closing (Załęski, 2002; Martone *et al.*, 2010; Poppinga *et al.*, 2017). There are three groups of activities for seed extraction from larch cones in extractories. The first group encompasses the receipt, weighing, cleaning, and storage of cones (Sarnowska and Więsik, 1997). The second group of activities consists of the thermal extraction and tumbling of cones. The third group involves seed dewinging, cleaning, separation, and storage as well as the disposal of waste, that is, spent cones, which may be sold or burnt (Aniszewska, 2008) (they can be utilized for energy generation purposes) (Aniszewska *et al.*, 2017).

The objective of the present study was to compare two methods of extracting seeds from larch cones: a thermal process with moistening and a thermomechanical process involving crushing. The processes differed with regard to the second group of activities and in dewinging, which in the thermomechanical method occurs together with the crushing of cones scales. The study was conducted in two seed extractories in Poland. In the thermal method, the cones are alternately dried and moistened (Aniszewska, 2008; Ilmurzyński, 1969). The initial drying temperature of 35°C is gradually ramped up to 50°C (Tyszkiewicz and Tomanek, 1946) to prevent thermal damage to the seeds. The cones can be moistened by soaking or spraying with water. This process yields seeds that meet the criteria of quality class I (Załęski and Aniśko, 2003).

In the thermomechanical process, the cones are dried for an extended period of time, and after the moisture content has been substantially reduced, the scales are crushed to extract the seeds (Suszka, 2000; Tyszkiewicz, 1951; Załęski, 2002). The crushing procedure makes it possible to release all of the seeds from a cone (Antosiewicz and Załęski, 1987). On the other hand, the abrasive elements of the mechanical crusher unit can damage the seed coat (Załęski, 2002; Kowalczuk, 1999; Pecen, 1994). Moreover, the extracted seeds need to be separated from a mixture of dust and scale fragments which are similar in size to the seeds (Załęski, 2002). It is also necessary to separate the empty seeds, which account for up to 70% of the total (Kosiński, 1987) from the full seeds, which have a similar weight (Aniszewska, 2008; Załęski and Aniśko, 2003).

In addition, it should be noted that while mechanical cone crushing may lead to a high yield, the seeds obtained using this method are characterized by a lower viability upon storage and lower resistance to stress conditions as compared to the seeds obtained through thermal extraction (Załęski, 2002; Antosiewicz and Załęski, 1987). Thermomechanically extracted seeds have been reported to exhibit a higher rate of electrolyte loss, which is a manifestation of substantial damage to their cell structure due to the scale of crushing and abrasion in the crushing units (Załęski, 2002). Such seeds should be sown shortly after extraction as they are not suitable for long-term storage (Aniszewska, 2008). Moreover, another study recommends that larch seeds intended for long-term storage should not be dewinged because the very process of breaking off seed wings while the seed is in a dry state may damage the seed coat (Więsik and Aniszewska, 2011; Aniszewska, 2014).

The production capacity of Polish extraction facilities on average amounts to 5-8 kg of seeds per 100 kg of cones, depending on the genetic and environmental determinants (Chałupka *et al.*, 2011).

To date, no detailed analysis of seed extraction from European larch cones in silvicultural extractories has been published. The objective of the current work was to compare two methods used by the following facilities: the Czarna Białostocka Extractory and the Forest Seed Centre in Równe. The paper analyzes the parameters of the extraction process as well as the quantity and quality of the seeds obtained using the two methods studied.

MATERIALS AND METHODS

The study involved individual cones and batches of cones placed in extraction cabinets in two silvicultural extractories (geographic locations: 52°41′0 N, 23°60′ E and 50°10′ N, 22°20′0 E). The case study of the thermal extraction method involved 160 kg of European larch cones (LMR MP/3/41001/05), of which 150 cones were examined individually. The case study of the thermomechanical extraction method involved 115 kg of European larch cones (LMR MP/3/41061/05), of which 120 cones were analyzed in detail.

The height (h) and diameter (d) of individual cones were measured using an electronic caliper (model 677256, Silverline Tools, Yeovil, United Kingdom) with an accuracy of ±0.1 mm, while their initial weight m_0 was taken using a laboratory balance (model WPS210S, Radwag, Radom, Poland) with an accuracy of ±0.001 g.

In both cases, the drying processes conducted in the extraction cabinet were investigated and the individual cones were examined. The latter were placed in bags made from thin landscape fabric (P-17) and placed on screens, which were then transferred to the cabinet. In the course of the drying process, the cones were removed from the cabinet every 2 h and weighed using a laboratory balance (model WPS210S Radwag, Radom, Poland) (±0.001 g). The measurement procedure took approx. 15 min.

Prior to seed extraction, the cones were separated from the coarse debris (stalks, needles, and the remains of branches) in a cone handling unit with a roller feeder (Nomeko, Umeå, Sweden). Subsequently, 40 kg of cones were placed in each of four containers and inserted into a seed extraction cabinet model BW 1600 (Nomeko, Umeå, Sweden). The cones were dried using a program dedicated to processing pine cones, which ramped up the temperature to approx. 35°C over the first two hours, and then gradually to 50°C. The hourly power consumption of the cabinet was 20 kW. After 10 h of drying, the cones from each of the containers were placed in a rotary drum model BGL20-01-4000-600 (Nomeko, Umeå, Sweden) for 7 min, which was set to 10 rpm to release seeds by tumbling. Next, the cones in the containers (with slots) were sprinkled with a stream of running water, approx. 10 L per container. The cones were left for 10 h to absorb moisture. The process of drying the cones in a cabinet and tumbling them in the drum was repeated on the following day.

The obtained seeds were transferred to a dewinger (Nomeko, Umeå, Sweden) for wet dewinging. In Czarna Białostocka, a dewinger is used to dewing larch seeds, it is also used to separate the wings from pine and spruce seeds. The seeds of pine and spruce are sprinkled with water prior to dewinging. In the case of larch seeds, no initial sprinkling is performed, while rubber plugs are poured into the drum of the dewinging machine. During the process the plugs rub against the seeds, which increases the efficiency of the process of breaking off the larch wings. After 50 min, the dewinger was tilted from 30 to 90° for 10 min to separate the wings from the seeds under airflow. The dewinged seeds were placed in a vibration screen separator model LASOL–F (Damas, Feeborg, Denmark) with mesh sizes of 4, 4, and 3 mm in order to obtain three fractions (coarse debris, full and empty seeds, and fine impurities). This step lasted for 15 min for each 10 kg of load. Subsequently, the seed fraction was transferred into a seed dryer model DC 200/400 (Nomeko, Umeå, Sweden) to obtain an appropriate moisture content of approx. 5% (60 min). Finally, the seeds were placed in a pneumatic separator model LASTI (Damas, Feeborg, Denmark) in order to separate the empty seeds from the full ones at an airflow rate of 10 m s^{-1}.

After the first day of drying, the seeds that were released by individual cones into bags were tallied, and the cones were sprinkled with water to close the scales and left for 10 h.

A cone handling model 356-01 unit with a roller separator model 357-01 (BCC AB, Landskrona, Sweden) was used for the preliminary separation of the cones from impurities. Subsequently, 11.5 kg of cones were placed in each of 10 containers, which were then inserted into a seed extraction cabinet model DL 1200/38 HL 402-01 (BCC AB, Landskrona, Sweden), which requires 25 kW per h.

The cones were subjected to an automatically controlled drying process in the extraction cabinet. Over the course of almost 30 h, the temperature was gradually ramped up to approx. 50°C, and the air humidity was decreased to 12%. Over the next 10 h, the cabinet heaters were turned on only if the air humidity increased, thereby maintaining it at a constant level. After 40 h in the cabinet, the cones were transferred to extraction drum model 401-SS (BCC AB, Landskrona, Sweden) where 50 kg of cones were tumbled for 2 h at 40 rpm to extract the seeds. Subsequently, the cones were divided into 10 kg batches, packed into cotton bags and subsequently placed in mechanical seed extractor model TD (Tyszkiewicz-Drachal) for a 20 min crushing treatment. The obtained seeds with impurities were transferred to a vibrating screen separator model 423-SS (BCC AB, Landskrona, Sweden) with screen meshes of 4 mm and 1.5 mm to obtain three fractions (coarse debris, full and empty seeds, and fine impurities). This step lasted for 30 min for each 10 kg load. Finally, the seeds were transferred to a pneumatic separator model 422-SS (BCC AB, Landskrona, Sweden) to separate the full seeds from the empty seeds at an airflow rate of 25 m s^{-1}.

The individually examined cones in bags were not subjected to tumbling in the drum or crushing in the mechanical seed extractor; instead, all of the seeds were removed from them manually.

Following seed extraction, all of the cones originating from two sources were evaluated in terms of the number and weight of the obtained seeds m_n using a laboratory balance model WPS210S (Radwag, Radom, Poland) with an accuracy of ±0.001 g. Next, the cones were dried to a dry weight at 105°C (±2) in an oven dryer, using the dryer-weighing method according to the standard (EN 13183-1:2004, 2004), which made it possible to calculate the initial and final moisture content and determine the instantaneous cone moisture content throughout the process.

In the case of both of the methods studied, changes in cone moisture content during seed extraction were described using Lewis's empirical model for the second stage of drying (Aniszewska, 2008; Pabis, 1982; Pabis and Henderson, 1961).

The seeds obtained using the two methods were compared in terms of viability (germination energy and capacity). The following coefficients were calculated: seed yield (α), cone mass yield (β), $M_{1000\ seeds}$, and process efficiency W_d.

The seeds obtained using the studied methods were placed in a Jacobsen germinator (Laborset, Łódź, Poland) in four 100-seed replicates, using the same laboratory equipment used in other studies (Tulska *et al.*, 2021). Germination energy was measured on day 7 and germination capacity on day 21 of the experiment, which was the basis for the seed quality classification (PN-R-65700; ISTA, 2018).

Process efficiency W_d was computed using Eq. (1) based on the weight of the fraction of full seeds cleaned in a pneumatic separator and the weight of cones with seeds that were placed in the extraction cabinet (measured before extraction) (Załęski *et al.*, 2000). In the case of the yield of larch cones expressed in terms of the weight of the obtained seeds per unit of cone mass, the actual weight of the cones was converted to the weight of cones with a 20% moisture content:

$$W_d = \frac{m_n}{M} 100, \tag{1}$$

where: m_n – weight of the obtained seeds after cleaning (kg), M – weight of the cones at a moisture content of 20% (kg).

The dynamics of seed extraction were evaluated based on the number and weight of the seeds obtained from individual cones in bags, these results were used to compute the seed yield coefficient α Eq. (2) and the cone mass yield coefficient β Eq. (3) but only for the step of seed extraction in the cabinet, without tumbling and crushing:

$$\alpha = \frac{l_n}{l_w}, \tag{2}$$

where: l_n – number of extracted seeds, l_w – number of all seeds in the cone,

$$\beta = \frac{m_n}{m_0}, \tag{3}$$

where: m_n – weight of extracted seeds (g), m_0 – initial cone weight (g).

After completing the extraction process, the number of open cone scales was tallied as each scale is capable of releasing two seeds (as a morphological determinant of seed extraction).

In addition, the study measured the $M_{1000\ seeds}$ parameters for seed lots obtained using the two methods, this was based on the average weight of four 100-seed replicates.

A statistical analysis was conducted using Statistica v. 13.3 software (Statistica, 2017). The normality of distribution of the cone size and weight parameters was evaluated using the Shapiro-Wilk test. Differences in the mean cone size and weight parameters as well as in the number and weight of the seeds were evaluated by means of an analysis of variance using a Student's *t*-test as well as a test for independent samples (*F* ANOVA). All tests were conducted at a statistical significance level of 0.05.

RESULTS

An analysis of variance (ANOVA) showed that cones from the two extractories differed significantly from each other in terms of: height (F=37.49, p=0.00), diameter (F=59.77, p=0.00), weight (F=26.16, p=0.000), and moisture content (F=1231.45, p=0.000).

Table 1 presents mean values with standard deviations, coefficients of variation, and standard errors for individual batches of the studied cones from two sources that were subjected to thermal (*t.*) and thermomechanical (*tm.*) extraction. The Shapiro-Wilk's test shows that the parameters are characterized by a normal distribution.

The parameters of the studied cones were within the ranges reported by other researchers (Więsik and Aniszewska, 2011), that is, h = 30-50 mm, d = 20-30 mm, m_0 = 1.0-7.0 g, and l_{scales} = 35-70, with the exception of the height of the cones that were subjected to the thermomechanical process (shorter). On average, the cones that were processed with the thermal method contained fewer seeds (l_w), than those processed using the thermomechanical method. Two geographically different locations of seed plantations could be the reason for the varying physical property of the larch cones.

Table 1. Parameters of the cones subjected to thermal and thermomechanical extraction methods and parameters of the extracted seeds

Parameter	Mean (±SD)		CV		Standard error	
	t.	*tm.*	*t.*	*tm.*	*t.*	*tm.*
Height h (mm)	31.04±4.05	28.04±3.93	13.06	14.02	0.33	0.36
Diameter d (mm)	16.75±1.76	18.41±1.76	10.50	9.54	0.14	0.16
Initial weight m_0 (g)	3.663±1.143	2.976±1.035	31.22	34.77	0.093	0.094
Moisture content W (%)	41.55±4.82	22.80±3.71	11.60	16.29	0.39	0.34
Number of scales l_{scales}	53±8	49±8	16	17	1	1
Number of seeds per cone l_w	32±15	60±16	45	27	1	1
Number of extracted seeds l_n	15±12	11±10	80	99	1	1
Weight of extracted seeds m_n (g)	0.078±0.060	0.052±0.055	76.70	105.7	0.005	0.005

t. – thermal method; *tm.* – thermomechanical method, SD – standard deviation, CV – coefficient of variation.

Evaluation covered the number (l_n) and weight (m_n) of the seeds that were obtained from the extraction cabinets. On average, individually examined cones processed with the thermal method were heavier but contained fewer seeds than cones subjected to the thermomechanical method. The yield from the former cones (dried and moistened) was 50% of all seeds as compared to only 20% from the latter cones (without any tumbling or crushing treatments).

The overall time of the thermal process was 38 h and that of the thermomechanical process was 48 h. The steps of the two extraction methods are presented in the form of Gantt charts (Fig. 1).

high mean initial moisture content of the thermally extracted cones, and therefore a two-step drying process with a variable temperature was applied.

Using a previously verified model (Pabis, 1982; Pabis and Henderson, 1961), changes in moisture content were described for the studied batches of cones. This is of importance with a view to determining the appropriate temperature and moisture conditions, and finally developing a software algorithm to control larch cone processing in extraction cabinets.

The mean b coefficient characterizing changes in the moisture content of cones subjected to thermal extraction

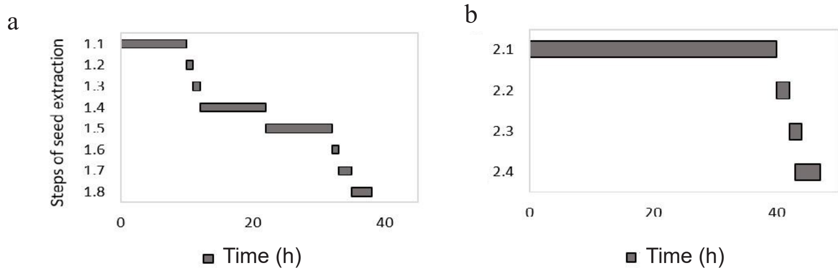

Fig. 1. Gantt charts showing the steps comprising the thermal (a) and thermomechanical (b) seed extraction methods: 1.1, 1.5, 2.1 – extraction in a cabinet; 1.2, 1.6, 2.2 – tumbling in a drum; 1.3 – moistening; 1.4 – moisture absorption; 1.7 – dewinging; 1.8, 2.4 – seed cleaning and separation; 2.3 – crushing in a mechanical extraction unit.

In the case of the thermal method, the time of seed extraction in the cabinet was 10 h on day 1 and 10 h on day 2, and in the case of the thermomechanical method it was 40 h in one cycle. Next, in both extraction methods the cones were tumbled in a drum: for 1 h in the thermal method and for 2 h in the thermomechanical one. In the thermal process the cones were additionally moistened and left to absorb moisture (10 h) and dewinged (2 h). In turn, the thermomechanical process involved crushing the cones in a mechanical extraction unit (2 h). Seed cleaning and separation took 3 h in the thermal method and 4 h in the thermomechanical one.

Table 2 presents changes in the moisture content (mean values with standard deviations $u \pm$ SD), minima (u min) and maxima (u max), as well as b coefficient values recorded in the process of seed extraction from individually examined cones subjected to extraction using the two methods studied.

The mean initial moisture content of cones subjected to thermal extraction ($u_{0t.}$) was 0.387 [kg_{water} kg^{-1}_{dw}] on day 1 and 0.456 [kg_{water} kg^{-1}_{dw}] on day 2. In comparison, the mean initial moisture content of the cones subjected to thermomechanical extraction ($u_{0tm.}$) was 0.228 [kg_{water} kg^{-1}_{dw}]. The mean final moisture content of the cones subjected to thermal extraction ($u_{kt.}$) was 0.073 [kg_{water} kg^{-1}_{dw}] on day 1 and 0.127 [kg_{water} kg^{-1}_{dw}] on day 2. The same parameter for the cones subjected to thermomechanical extraction ($u_{ktm.}$) was 0.096 [kg_{water} kg^{-1}_{dw}]. Special care had to be taken due to the

on day 1 and 2 was $b_{1t.} = 0.29 \pm 0.04$ and $b_{2t.} = 0.26 \pm 0.06$, respectively. In turn, the mean b coefficient for the moisture content of cones subjected to thermomechanical extraction was $b_{tm.} = 0.13 \pm 0.01$. The mean value of $b_{tm.}$ was lower than that of $b_{1t.}$ or $b_{2t.}$ because in the thermomechanical process the drying step lasted for four times longer as compared to one drying step (on one day) in the case of the thermal process.

Figure 2 shows examples of the model and the actual curves representing changes in the mean moisture content for a cone subjected to thermal extraction (a) and thermomechanical extraction (b).

The drying process was described by equations for changes in moisture content (Aniszewska, 2008) using the dryer-weighing method, where τ is seed extraction time. The following equations were obtained for the thermal method (4 and 5):

$$\text{Day 1: } u_{1t.} = 0.314e^{(-0.29\,\tau_i)} + 0.073, \tag{4}$$

$$\text{Day 2: } u_{2t.} = 0.329e^{(-0.26\,\tau_i)} + 0.127, \tag{5}$$

and for the thermomechanical method (6):

$$u_{tm.} = 0.132e^{(-0.13\,\tau_i)} + 0.096. \tag{6}$$

On day 1 of the thermal process 3.55 kg of seeds was obtained after 10 h of drying followed by cone tumbling in a drum. At the end of day 1, the weight of cones decreased

Table 2. Basic parameters of seed extraction with the two studied methods

Day	Time (h)	$u \pm$ SD	u min	u max	b (h^{-1})
		[kg_{water} $kg^{-1}{}_{dw}$]			
		Thermal method			
1	0	0.387±0.043	0.288	0.493	-
	2	0.277±0.047	0.154	0.459	0.22±0.08
	4	0.180±0.042	0.095	0.357	0.28±0.09
	6	0.124±0.029	0.058	0.260	0.31±0.07
	8	0.095±0.020	0.050	0.185	0.35±0.09
	10	0.073±0.015	0.036	0.120	0.57±0.02
2	0	0.456±0.048	0.239	0.499	-
	2	0.351±0.066	0.173	0.464	0.20±0.13
	4	0.272±0.067	0.101	0.430	0.21±0.10
	6	0.213±0.053	0.081	0.357	0.23±0.08
	8	0.165±0.042	0.059	0.260	0.28±0.10
	10	0.127±0.024	0.042	0.174	0.58±0.02
		Thermomechanical method			
	0	0.228±0.037	0.130	0.399	-
	2	0.195±0.035	0.102	0.338	0.14±0.04
	4	0.166±0.033	0.073	0.289	0.16±0.06
	6	0.146±0.032	0.055	0.258	0.17±0.07
	8	0.132±0.033	0.042	0.232	0.17±0.03
	10	0.121±0.031	0.032	0.207	0.17±0.02
	18	0.107±0.031	0.021	0.232	0.14±0.02
	20	0.107±0.035	0.023	0.331	0.13±0.02
	22	0.105±0.031	0.023	0.197	0.12±0.02
	24	0.104±0.031	0.021	0.196	0.12±0.02
	26	0.103±0.031	0.020	0.195	0.12±0.01
	28	0.103±0.031	0.020	0.195	0.11±0.02
	30	0.101±0.032	0.018	0.189	0.12±0.02
	32	0.100±0.031	0.017	0.192	0.11±0.02
	40	0.096±0.031	0.015	0.188	0.12±0.02

u – cone moisture content, SD – standard deviation, min, max – minimum, maximum, b – coefficient characterizing moisture content change.

by approx. 25%. On day 2, the same process resulted in the separation of 1.34 kg of seeds (a total of 4.89 kg of seeds with wings were obtained during the two days). After dewinging, the resulting 3.27 kg of seeds was first separated in a screen separator (2.78 kg were obtained), and then in a pneumatic one. Finally, 1.98 kg of full seeds was obtained from 160 kg of larch cones with an initial moisture content of 41.55% (± 4.82).

In the case of the thermomechanical method, 40 h of drying followed by cone tumbling in a drum resulted in 0.60 kg of seeds with impurities as well as 70.40 kg of cones for crushing; this yielded 14.60 kg of seeds with impurities, which were combined with the previous batch (0.60 kg) and separated with screen and pneumatic separators. This process yielded 4.46 kg of full seeds with wings from 115 kg of cones with an initial moisture content of 22.80% (±3.71).

Table 3 provides the germination energy and capacity for the seeds obtained from processes carried out using the two studied extraction methods performed at two extractories.

The germination energy and capacity of the studied seeds at various processing steps were lower for the thermal method than for the thermomechanical one. The germination parameters of the control sample for the former method were lower than those for the latter method due to the considerable number of empty seeds in the cones

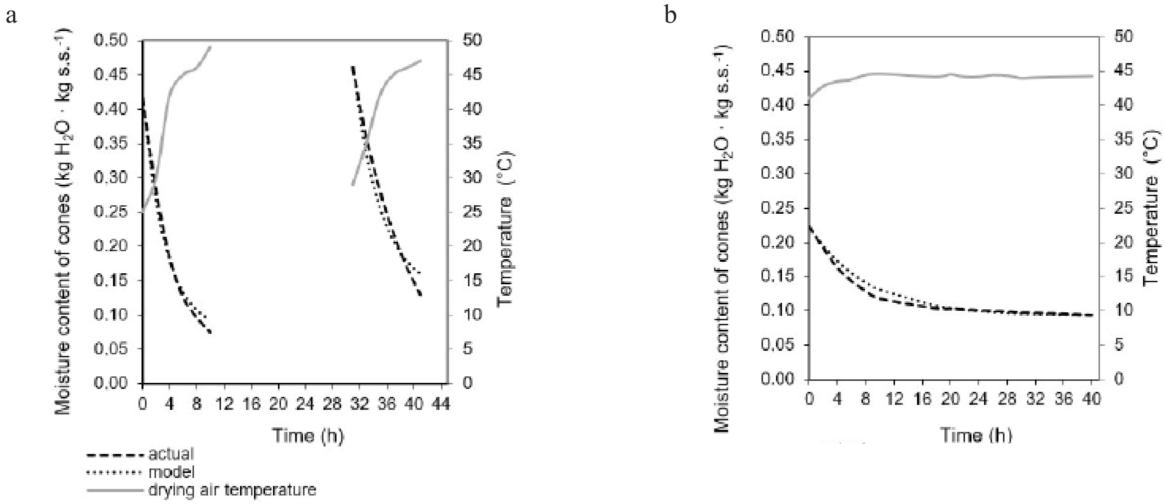

Fig. 2. Drying air temperature and mean moisture content of a sample cone (actual and model) for: a – thermal seed extraction, b – thermomechanical seed extraction.

Table 3. Comparison between the germination energy and the capacity of seeds obtained using the two studied extraction methods at different steps of seed processing

Seed processing stage after	Thermal seed extraction			Thermomechanical extraction		
	Germination		Quality class	Germination		Quality class
	energy	capacity		energy	capacity	
Cone tumbling	Day 1 – 35 Day 2 – 26	Day 1 – 35 Day 2 – 26	II II	48	48	I I
Mechanical crushing	-	-	-	41	42	I
Separation in						
screen separator	39	40	II	49	49	I
pneumatic separator (full seeds)	41	41	I	57	58	I
Control – manually extracted	41	41	I	58	58	I

used. The cones from that source were characterized by a lower genetic potential (they were also assigned to a lower quality class after tumbling and dewinging).

In the thermomechanical method, the germination energy and capacity of the seeds after mechanical cone crushing was lower than at the other stages of the process. In addition, an examination of the purity of the seed sample after crushing revealed a higher proportion of halved or fragmented seeds than after the other steps. Seeds that are damaged in this way are not suitable for sowing. On the other hand, even the slightest damage to the seed coat makes long-term storage impossible (similar to that caused by drying the cones at a high temperature of up to 60°C) (Załęski, 2002; Aniszewska, 2014).

The overall high germination energy and capacity values (less than 40%) indicate that the separation step was carried out appropriately using both methods, and the resulting seeds were categorized as quality class I (the highest possible) according to the current standards. In larch, germination energy and capacity values ranging from 40-26% indicate seeds of the II quality class, while 25-10% includes seeds of the III quality class (PN-R-65700, 1998; Załęski, 1995).

The energy consumption for the thermal method of seed extraction in the cabinet was approx. 400 kWh (20 h × 20 kW), while that for the thermomechanical method was approx. 1 000 kWh (40 h × 25 kW).

DISCUSSION

Making a comparison between the thermal and thermomechanical methods in terms of the extraction process steps as well as between the quality and quantity of the obtained seeds is not straightforward.

The process effectiveness W_d which was calculated from Eq. (1) was 2.57 and 4.42% for the thermal and thermomechanical methods, respectively. However, it should be noted that the cones subjected to thermal extraction had been collected from felled trees in a plantation that was being liquidated. Therefore, that batch of cones contained both the current year's cones with seeds and empty cones from previous years. Moreover, the better developed cones (Tyszkiewicz, 1951) are characterized by greater seed yields. In other studies the yields of seeds from 100 kg of European larch cones have been reported to be 7.5% (Tyszkiewicz, 1951), 5-8% (Kocięcki, 1966) and 3.2-9.0% (on average 5.8%) (Rohmeder, 1972).

It has been reported that the seeds obtained using the thermal method are easier to clean with the aim of achieving almost 100% purity (Załęski, 2002). Special care must be taken while using the thermomechanical method as the dust produced in the crushing step is explosive and the process of obtaining a high degree of seed purity is both time and energy intensive.

The seed yield coefficient $\alpha_{t.}$ (Eq. (2)) was 0.42 ± 0.23 for 150 individually examined cones subjected to thermal extraction (with moistening), while the corresponding coefficient $\alpha_{tm.}$ (Eq. (2)) for 120 individually examined cones subjected to thermomechanical extraction (without crushing) was 0.17 ± 0.16. The mass yield coefficients for the same cones were 0.022 ± 0.018 in the case of thermal extraction and 0.019 ± 0.020 in the case of thermomechanical extraction ($\beta_{t.}$ and $\beta_{tm.}$ were calculated from Eq. (3), respectively). These results are consistent with the findings of other researchers in that a long period of drying in itself does not increase the rate of ejection of seeds from larch cones (Załęski, 2002; Tyszkiewicz, 1951). On the other hand, the rate of seed extraction is increased by repeated alternating cycles of cone moistening and drying (Aniszewska, 2008).

The weight of 1000 dewinged seeds ($M_{1000\ seeds}$) was 5.762 g for the thermal method and 4.717 g for the thermomechanical method. The values of $M_{1000\ seeds}$ that were obtained using both methods were within the range reported by other authors, that is, 2.2-8.8 g (Antosiewicz, 1970) and 2.0-5.5 g (Więsik and Aniszewska, 2011). Yet another study reported mean $M_{1000\ seeds}$ values of 6.1 g and approx. 5.0 g for larch seeds with and without wings (Aniszewska, 2008).

The greater viability of the larch seeds obtained using the thermal method indicates that despite a lower seed yield this process should be used in situations where the seeds are to remain in long-term storage, *e.g.*, in forest gene banks. In turn, thermomechanical seed extraction can be used to obtain seeds for short-term silvicultural needs (*e.g.*, forest regeneration).

Taking into consideration the energy consumption of the extraction process and the quality requirements of seeds for long-term storage, the thermal extraction method is recommended for silvicultural extraction facilities. A further comparative study of thermal and thermomechanical processes should be conducted using cones from one source to avoid significant differences in size, weight, and initial moisture content parameters.

CONCLUSIONS

1. The process of seed extraction was shorter by 20 h in the case of the thermal method and required less electrical energy (by 600 kWh) as compared to the thermomechanical method. However, the shorter process time may have affected the quantity of the obtained seeds, this is confirmed by the relatively high moisture content in cones after the second day of the thermal process.

2. In order to improve the efficiency of thermal seed extraction, the recommend procedure consists of three drying cycles in the extraction cabinet alternated with two moistening treatments (the duration of the overall process amounts to three days). This method yields a greater number of seeds suitable for long-term storage. In the case of larch cones from some sources one moistening treatment may be insufficient.

3. The seeds obtained from both case studies meet the requirements of quality class I. The yield of seeds from two different sources was higher for the thermomechanical method as compared to the thermal extraction. However, this result was considerably affected by the significantly greater number of seeds found in the cones subjected to thermomechanical extraction (by as much as 50%) and the crushing treatment, which was absent from the thermal method. It should be borne in mind that according to the literature, crushing has an adverse effect on the quality of seeds designated for storage and should be applied only when the seeds are to be sown in the year of the next harvest.

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