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Automation of the Acorn Scarification Process as a Contribution to Sustainable Forest Management. Case Study: Common Oak

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Abstract: The basic principle of silviculture is the rational use of natural regeneration. The acceleration and equalisation of seed germination and an increase of the field seed germination ability are affected by seed scarification, which results in the destruction or weakening of the seed cover. Acorn scarification is performed manually, in the standing position, most often in adapted work stations, whose geometry is adjusted by the staff to their own anthropometric dimensions. An added value of acorn scarification consists in the ability to visually assess the health status of the cotyledons visible on the cross-section, making it possible to infer the potential use of a seed for sowing. However, due to the scope and duration of the activities involved, manual scarification is a process that is monotonous and physically as well as psychologically tiring for its performer. Automating of this process allows for effective replacement of human labour. The results obtained from the use of the vision system designed to determine the length and orientation of acorns may be considered satisfactory. The implementation of the seed orientation detection algorithm using the Harris detector was 90% accurate. Studies and analyses have shown that the process of acorn scarification has a positive effect on the later improvement of uniformity and acceleration of seedling emergence. In the case of seeds subjected to scarification, 83% of the acorns germinated within 4 to 6 weeks after sowing.

Keywords: sustainable forestry; seedling; acorn; scarification; automatic device

1. Introduction

Modern, sustainable forest management consists of protecting and shaping the natural environment through its utilisation. In highly developed countries, such management is based on implementation of the following four objectives: (1) preserving forest biodiversity; (2) protection of forests by virtue of their cultural, recreational, landscape and scientific values; (3) protecting forests against industrial emissions; (4) harvesting of timber and other forest products [1–3]. Timber harvesting is closely associated with treatments leading to forest regeneration, which is the process of creating a young generation of trees in a forest area in place of the forest that is receding due to its use or damage, e.g., by fires, massive appearance of insects, climatic factors, etc. [4,5].

The process of regeneration may involve the forces of nature, i.e., natural regeneration, or the contribution of human labour, i.e., artificial regeneration. The basic principle of silviculture is the rational use of natural regeneration. However, it should be noted that silviculture should only be used in the case of good quality of the parent stands [1,6]. Moreover, the drawbacks of natural regeneration include: (1) dependence on seed years; (2) unevenness of sowing, resulting in laborious and costly re-sowing; and (3) the lack of desired tree species, in the maternal stand. Natural regeneration usually ranges from several to several dozen percent of the total area [6,7]. Obtaining good quality natural regeneration in the case of the common oak (*Quercus robur* L.) is particularly difficult and requires from foresters vast knowledge and experience on the part of foresters. Seeds have a clearly defined period of appearance, and their survival is limited due to pathogenic fungal infections and to the fact that they are a good feeding base for rodents and wild boars [8–10]. In addition, after acorn germination, seedlings often die as a result of over-shading or excessively concise soil, which makes their rooting difficult [11]. In view of the above, artificial regeneration is commonly used for common oak, and seedlings are increasingly grown in container nurseries [12,13]. Sometimes direct sowing of acorns is performed [14]. However, this species poses significant problems for nurseries as it is characterised by extremely uneven germination although the use of precision sowing contributes to the creation of identical growing conditions for seedlings. The first seeds start to germinate 2–3 weeks after sowing but the final ones can be even after 16–17 weeks. This results in the differentiated growth of seedlings and increases competition between them. The later seedlings remain under the cover of the larger ones with well-developed leaves which effectively limit the access to light and water [6,15]. In this way, nursery production favours the faster growing seedlings, due to which those growing slower yield to competition or are eliminated in the process of their sorting [16].

The acceleration of seed germination and increase of the field germination ability are affected by seed scarification consisting in the destruction or weakening of the seed cover [17]. This treatment allows for easier access to the water and air needed to initiate the germination phase of a seed. Under conditions of natural regeneration, scarification is possible due to factors such as changes in humidity, temperature or interference of soil microorganisms [18]. Under nursery conditions, artificial scarification is performed, which may consist in: (1) treating seeds with high temperature (short-term treatment with fire, hot water or microwave radiation), resulting in micro-cracks, generated by changes in mechanical stresses; (2) treating seeds with sulfuric acid for chemical degradation of the cover; (3) mechanically damaging the cover by crushing, abrading or cutting [19]. The latter type of scarification is commonly used in the case of oak acorns, which are cut on their distal side (the cup scar) by of 1/5 to 1/3 of the total length [20]. In Poland alone several dozens of millions of seeds are refined in this way. This usually takes about 3 months: from January to March. This tedious and monotonous job requires employing several people in each of the nurseries in the preparation of the oak seedlings. From the point of view of ergonomics, the arduousness of that work is related to arm and hand movements repeated several thousand times daily in the following cycle: (1) grabbing a seed (or several seeds) from a container with the hand; (2) cutting off a segment of the seed with pruning shears or a guillotine; (3) visual evaluation of the seed's germination ability, after its scarification, based on the colour of the cotyledons and the degree of their filling the seed coat; and (4) either transferring the seed to the sowing tray or its rejecting it. This causes fatigue to the nervous and muscular system of the hands and arms due to the repetitive labour.

It should be noted that maintaining the right proportion between the part of the acorn that is cut off and the part intended for sowing has important agrotechnological implications. Excessive scarification (removal of large parts of the cotyledons) results in the production of seedlings with abnormal morphological features. The cotyledons serve as nutrient storage, filling almost the entire interior of a seed [21]. Seedling growth in the juvenile phase is influenced by seed mass: seedlings grown from heavier seeds are characterised by a greater proportion of root length to shoot length, which suggests better production quality. The relationship between seed size and biomass distribution is particularly prominent in oak tree seedlings [20,22]. The scarification treatment, even of low intensity, has a positive effect on the effectiveness of fungicides, which which results in producing seedlings with higher quality [20]. An added value of applying acorn scarification is the possibility of visual assessment of the health condition of the cotyledons visible on the cross section, making it possible to infer the potential of seeds for sowing [23].

2. Materials and Methods

2.1. Research Material

The research material consisted of the seeds of common oak (*Quercus robur* L.). Acorns contain one non-endospermic seed with an embryo equipped with two massive cotyledons lying along the embryo axis. It is embedded in a scaly cup (the remains of the flower copula). The shape of common oak acorns is variable; the most common are cylindrical and elongated acorns, flat at the base, with a visible circular cup scar that is hidden under the copula while still in the tree. The apexes are gently pointed. The main physical features of the acorns can be found in Table 1. The acorn stalks of common oak are longer than of the sessile oak. The longitudinal stripes often visible on acorns are not a definitive feature of a given species. The morphological characteristic that allows for a clear distinction between the two species is the location of the largest diameter, which in this case usually falls on the centre of an acorn. It should be noted that at the time of scarification the acorns have already been protected against diseases and fungi with a substance which changes the colour of the acorn shell to red (Figure 1).

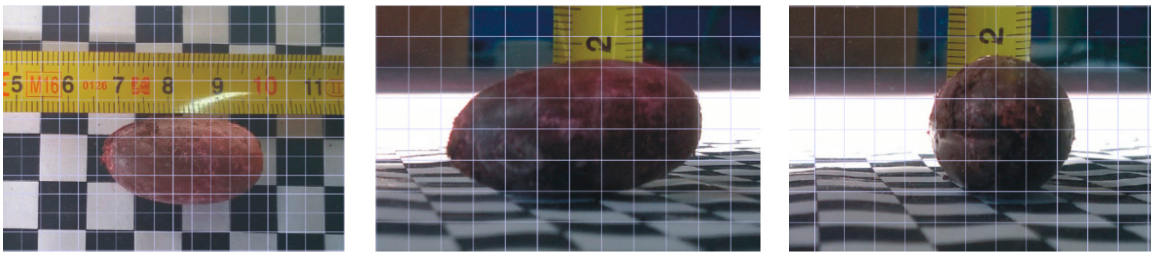


Figure 1. Acorns before scarification.

Table 1. Parameters of the assimilation apparatus of common oak seeds.

Physical Characteristics	Length (mm)	Width/Thickness (mm)	Mass (g)
	32.6 ± 2.82	17.4 ± 1.41	6.05 ± 1.36

2.2. Worksite Characteristics

Scarification is performed manually, most often with the help of pruning shears (Figure 2). This is a typical example of monotonous manual labour, done repeatedly, with well documented consequences.

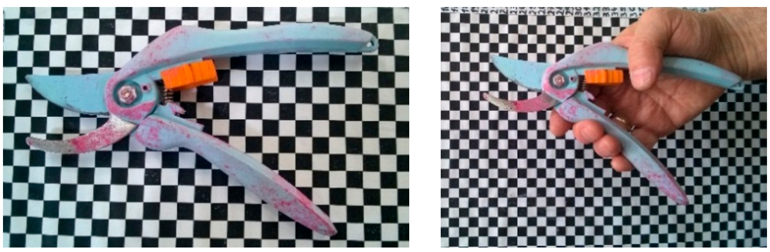


Figure 2. Pruning shears used for manual scarification of acorns.

Acorn scarification is usually performed in the standing position, most often at specially adapted work stations, whose geometry is adjusted by workers to their own anthropometric dimensions (Figure 3). The seeds are selected with the left hand from the container and grasped with the fingers. At a distance of about 1/5 of the length of the seed, it is cut using pruning shears and then visually evaluated for its suitability for planting. Only a light-coloured, single-colour seed promises a chance of proper growth of a seedling; dark cotyledons show fungus disease and such a seeds are rejected. Previous practical experiments show that the effectiveness of such visual recognition of oak seed germination ability is over 80% [23,24].

Figure 3. Manual acorn scarification: the body position during work, the geometry of a temporary worksite.

2.3. Methodology for Determining the Acorn Cutting Force

The research was performed using the MTS Insight 2 strength machine. In this case, it was equipped with a two-disc attachment (Figure 4) consisting of two discs with the scarifier handle placed between them, which performed acorn scarification. The force required to cause the scarifier knife movement was recorded with the aid of the above-mentioned strength machine, and the readings of the crushing force value as well as the calculation of the unit resistance of crushing were automatic. The operating speeds of the movement of the crushing plates were set at 1000 mm·min^{-1}. The beginning of the cutting time recording and the automatic cutting force measurement occurs at the moment when the moving plate makes contacts with the material. The movement speed of the plate is constant and the entire crushing process is recorded automatically and displayed on the monitor screen.

Figure 4. A station measuring the strength of the acorn cutting force.

The theoretical work cycle time (Figure 5)—t1–t7—was calculated using the Maynard method, known as Methods-Time Measurement (MTM). The method of elementary time and motion is based on predetermined time standards, these standards are based on the study of limb and eye motions, and consist of elements that last a fraction of a second. From these elements are created strings of activities: operations. It should be noted that a working motion is a short, complete motion, which in a typical form often repeats and directly affects the course of work or any action. An elementary motion is an isolated part of an isolated motion, which, independently of the course of work, results from the mechanics of human body movements. On the basis of his experience, F.B. Gilbreth established 17 elementary motions, called therbligs after his anagram [25,26]. The MTM approach is based on the assumption that the time it takes to do a particular job depends on the method chosen. The MTM method was first applied in 1948 and has subsequently been modified several times. Its creators (H.B. Maynard, G.J. Stegemerton and J.L. Schwab) adopted the following basis [27]: eight elementary hand motions: stretching, grasping, moving, joining and releasing (as the most frequent elementary motions, accounting for 70–80% of the total course) as well as pressing, separation and rotation—two visual functions: vision shift and control; and nine body motions (legs and the torso), including the motion of feet and legs, motions of the body with shifting and inclination of its axis. Motion time values were determined on the basis of film analysis under specific production conditions. The unit is a TMU (time measurement unit)—1/100,000 parts of an hour (0.036 s).

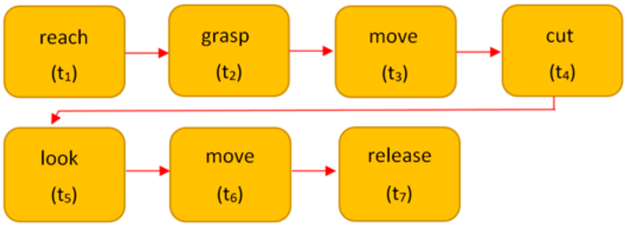


Figure 5. A work cycle with division into work elements (basic motions).

By filming the labour process of experienced staff and analysing the time-lapse film, the actual work cycle performance time was determined. The energy output during work was determined by the chronometric-tabular method (according to Lehmann). The spatial layout of the worksite was determined by performing measurements in a forest tree nursery (where acorn scarification is performed before sowing). The scarification force was calculated by measuring the force of cutting performed in the strength machine and the geometric dimensions of the pruning shears.

2.4. Measurement Results and Their Analysis

A comparison of the theoretical and actual cycle duration times is presented in Table 2.

Table 2. Parameters of the assimilation apparatus of common oak.

Determination of Activity Duration	Operation Time (mm)	
	Theoretically (TMU)	Theoretically (TMU)
t1	16.8	0.397
t2	7.3	0.103
t3	20.1	0.540
t4	10.6	0.696
t5	7.3	0.411 (good)
		0.541 (bad)
t6	20.1	0.311
t7	2.0	0.086
Total	84.2	2.544 (good)
		2.677 (bad)

Reaching for acorns with one's hand was performed along a path of ca. 45 cm; similar was moving the acorns to containers with seeds that either qualified for planting or were rejected. The theoretical duration of the cycle is over 3 s (84.2 × 0.036 s); therefore within 1 minute it is possible to scarify about 19 seeds. However, the time-lapse film analysis showed that the cutting time (PRESS the pruning shears t4) and the cotyledon assessment time (LOOK at the cut surface of a seed no. t5) are slightly shorter than the theoretical calculations. The total cycle duration time is practically shorter by about 0.48 s and takes about 2.54 s. Within 1 minute it is possible to scarify ca. 23 seeds.

The difference between the theoretical and the actual cycle duration time is therefore 0.48 s. If the total duration of the work cycle is ca. 2.544 s, the scarification of 1 million seeds takes 706.6 h (almost 89 days with 8 h per day). The maximal value of the hand pressure which the worker who scarified the acorns exerted on the scarifier amounted to an average of 15.2 N, which generated the cutting power of the scarifier blade amounting to 57 N. The energy expenditure associated with the work is the sum of energy expenditure for the assumed body position (2.51 kJ·min^{-1}) and the work of the fingers of both hands as well as the arms (8 kJ·min^{-1}). The net energy expenditure is therefore ca. 10.5 kJ·min^{-1}. Adding to the net energy expenditure the so-called basic metabolic rate (4.2 kJ·min^{-1} for women) allows for obtaining the gross energy expenditure (14.7 kJ·min^{-1}). According to Christensen's scale, manual acorn scarification is a light job. Within 8 h of work (with two leisure breaks, each of 15 min), the energy expenditure is 6.6 MJ.

The spatial layout of the worksite is presented in Figure 6. Acorn containers—before and after scarification—were placed within the reach of the workers' hands.

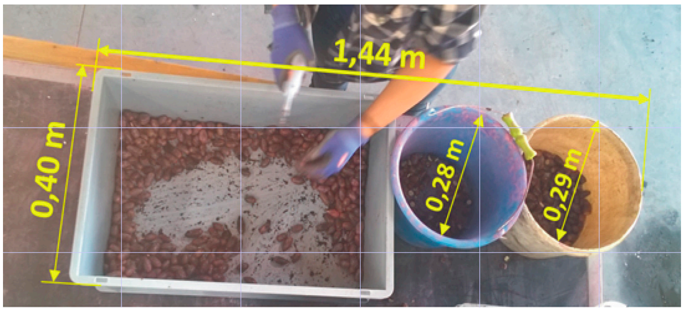


Figure 6. Spatial layout of the worksite.

3. Results

3.1. The Machine Vision System Designed to Determine Acorn Length and Orientation

3.1.1. General Structure of the Acorn Transport System, in Which Acorn Length and Orientation Are Determined

In order to correctly perform the task of automatic scarification of acorns, it is necessary to automatically assess their length and orientation. Acorns are delivered to the automatic device by means of a vibratory feeder (Figure 7), so that they appear at the inlet one by one. The orientation of their long axes in the direction of their movement is "generally" forcedby the V-shaped [28] structure of the singulator combined with an outlet of vibratory as well as further belt conveyor. The term "generally" in the preceding sentence indicates the case of a small percentage of spherical acorns (Figure 8 on the left) rather than the typically ecountered elongated ellipsoid ones (Figure 8 on the right).

Figure 7. The vibratory feeder for dosing seeds into the belt feeder.

Figure 8. Different shapes of acorns may cause their different behaviour in the course of feeding and transport.

3.1.2. Construction and Location of the Vision System

From the vibratory feeder, the acorns fall on the belt feeder—and here they are controlled by the first of two computer vision systems operating in the automatic device. This system continuously acquires images of the acorns being transported on the belt feeder by means of an appropriately positioned digital camera (Figure 9). The illumination subsystem is attached to the camera. Three types of LED (Light Emitting Diode) illuminator have been investigated at subsequent stages of the project development: a two direct linear illuminator (Figure 9), a custom shadeless linear diffuse dome illuminator (Figure 10), and a custom diffuse back light illuminator (Figure 11).

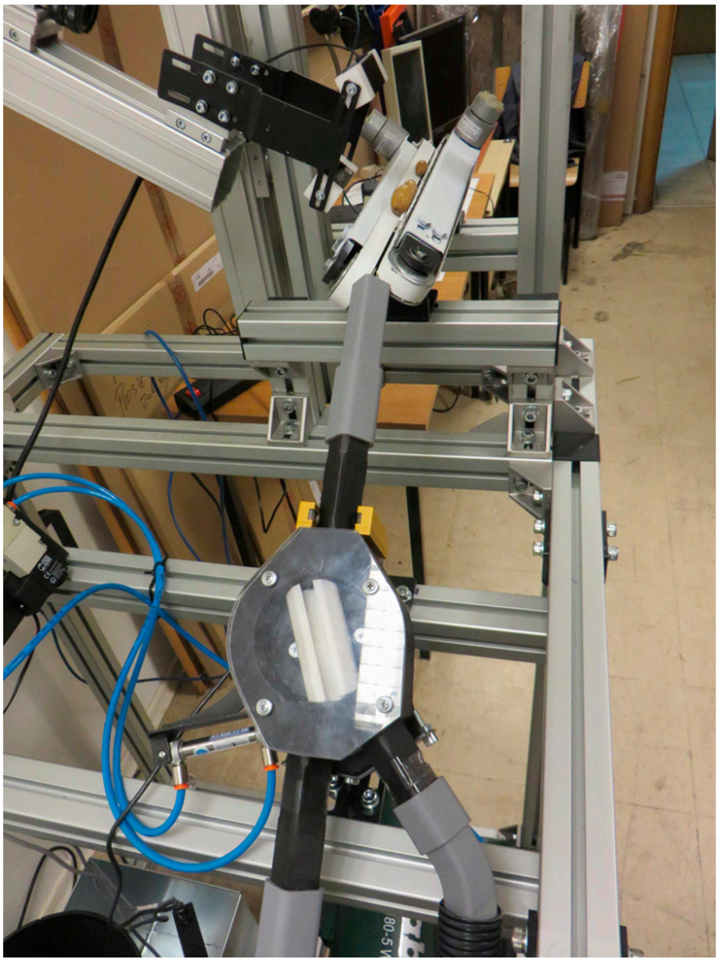
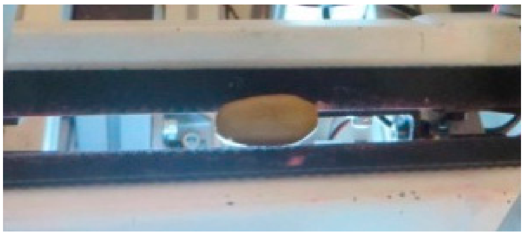


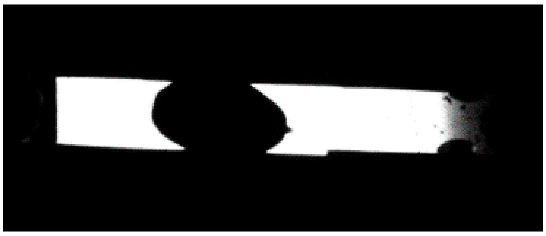
Figure 9. The setup of the camera focused on acorns being transported on the belt feeder.

Figure 10. The shadeless illuminator of the acorn orientation detection system. On the left—the photo with the illuminator switched off; on the right—with the illuminator switched on.

Since at this stage the only necessary information concerns the acorn contour, a monochrome camera is used, whose output signal (the image of the acorn being observed) is then binarised (Figure 11b) in the computer system.



(**a**)



(**b**)

Figure 11. The orientation detection module and seed length measurement: (**a**) a view of the belt feeder with a monochrome camera; (**b**) the acorn image acquired by the camera.

In order to be independent of the variability of natural lighting, which during device exploitation under the field conditions may vary in a fairly wide range of conditions, the camera that records the image of an acorn is accompanied by a special shadeless illuminator (Figure 10). In the next step a more robust back light illumination was examined (Figure 11a).

3.1.3. The Principle of System Operation

The tasks of the described system are related to the main objectives of the scarification process. It is to provide the automatic control system with information on the length and orientation of an acorn. The detection method used consists in converting a monochrome image into the binary form and to indicate the distance between two outermost points of the contour of a seed. The end of the section where the value of the Harris detector [23,29] reaches a higher positive value is assumed to be the embryonic root. Its situation relative to the seed centre indicates the orientation of an acorn.

Information on the orientation sent by the computer which analyses the image to the main controller of the device assumes a discrete form: (a) correct; (b) incorrect; (c) unrecognised. Seeds oriented correctly (i.e., the ones where the embryonic root is located at the front of the seed centre in the direction of movement on the belt feeder) pass through the orientator channel directly to the positioner. Seeds oriented incorrectly are rotated in the orientator by 180 degrees so that after the rotation the embryonic root is at the front in the direction of acorn transportation. On the other hand, seeds classified as unrecognised are rejected as unsuitable for scarification. They may be evaluated by hand, by qualified staff. As this concerns about 10% of the seeds, despite these rejections most of the work is done by the device. The orientator is presented in Figure 9 at its bottom. The general principle of orientation detection and seed length measurement is presented in Figure 12.

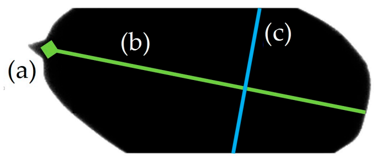


Figure 12. The general principle of orientation detection and seed length measurement as exemplified by a section of the image from the monochromatic camera: (**a**) the embryonic root; (**b**) the seed symmetry axis; (**c**) the designated plane of cotyledon cutting during scarification as a function of length.

Figure 13 shows subsequent stages of operation of the vision system described here. In the order from top to bottom, these are: a seed image obtained by the camera, segmented acorn, result of Harris operator, corner detection result along with contour of the seed determined by the gradient method, and the visual representation of acorn's length with marked marker.

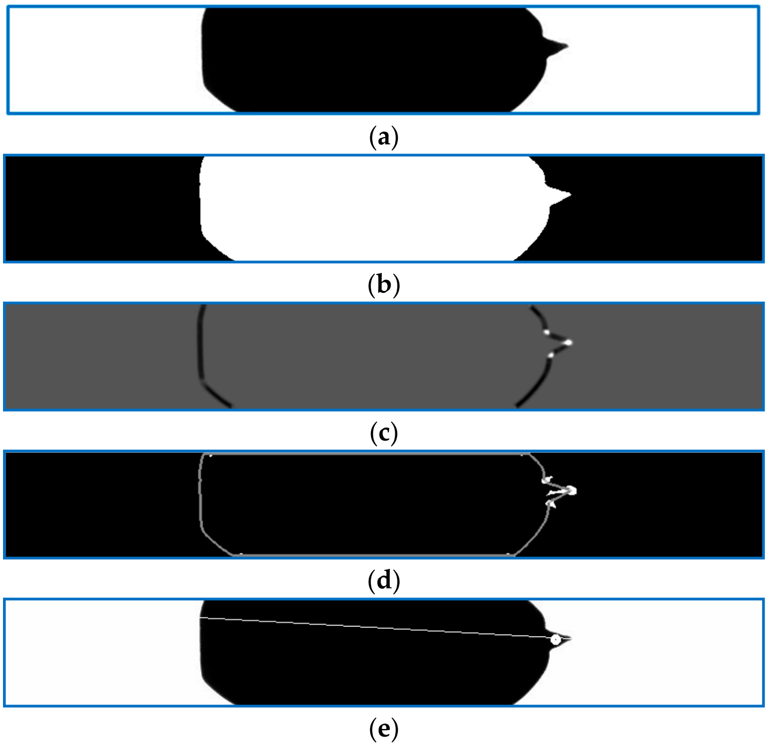


Figure 13. Stages of the process of seed orientation determination: (**a**) image acquired by the camera; (**b**) result of binary segmentation; (**c**) detection results provided by Harris operator (grey—no detection, white—corners, black—ridges); (**d**) corners (white) detected in the neighbourhood of edges (grey); (**e**) length of the acorn overlaid over input image with white line segment, detected orientation pointed by white dot.

The main purpose of the system is that the automatic device properly positions a seed for scarification: so that the cut is made on the correct side of an acorn and at the correct height. Due to the experimental nature of the automatic device under construction, the system additionally signals the result of its work on the control computer screen. An example of such a control image is shown in Figure 14. There is an image of an acorn ("caught during flight", because an acorn does not stop in front of the camera of the orientation detection system but is moving towards the orientator on the belt feeder) and a signal that it is positioned correctly. This signal is a green square in the upper left corner of the frame. In the case of an acorn that needs to be rotated, a red square appears in the upper right corner of the frame, and if the system does not recognise the position of an acorn (especially when there is no acorn in the field of view at a given moment as the transporter is empty) a yellow square appears in the centre of the frame. The signalling method described allows for immediate assessment of how the system works, which might be useful if the device began to make errors.

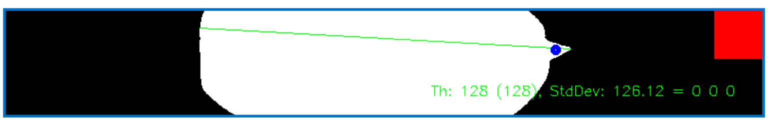


Figure 14. The signalling method on the screen of the computer that presents the results of the acorn orientation detection system: red rectangle notifies opposite orientation, green line segment shows the length of an object, blue dot points out the opposite end of the segment.

3.1.4. The Construction of the Scarification Unit of the Automatic Device

A properly oriented acorn is placed in the gripper, which, together with the swivel arm and the drive system, forms one of the units of the test model of the automatic device for acorn scarification (Figures 15 and 16). The gripper is attached to one end of the swivel arm and a suitable counterweight is attached to its opposite end. Due to the gripper construction and the kinematics of its movements, the diameter of the acorns being grasped determines its possible range of movement. The minimum grasp of the acorns by the gripper jaws is within a diameter range of 15 to 19 mm, with the possibility of extending it both downwards and upwards. The applied kinematic movement of the gripper arms also causes the lifting of the acorn while gripping and clamping. The height of this lift depends on the diameter of the acorn and its shape (a barrel-like shape). Small and slender acorns are lifted higher than large and barrel-like ones. The corresponding height of cutting the acorn cupule is adjusted by the positioner unit cooperating with the gripper, and consisting of a cam and its DC drive motor, attached to one handle (Figures 15 and 16). An acorn grasped by the jaws of the gripper is moved gripper moves to the scarification unit, which is formed by two counter-rotating disc knives. They are driven by two DC motors. The motors are attached to the frame elements with a handle. The construction of the handle allows for adjusting the mutual alignment of the knives.

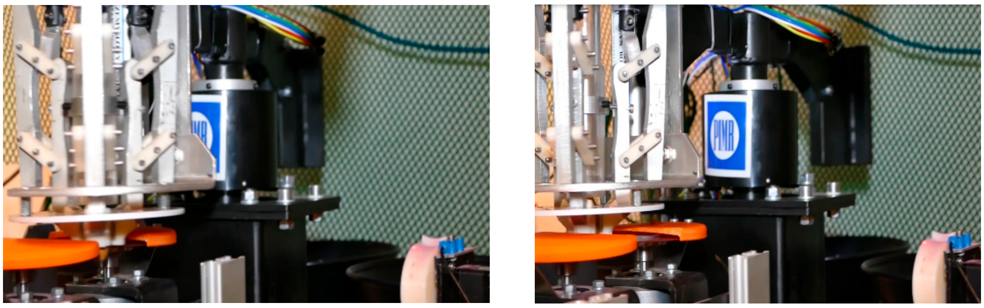


Figure 15. The scarification unit of the automatic device during stages of acorn scarification.

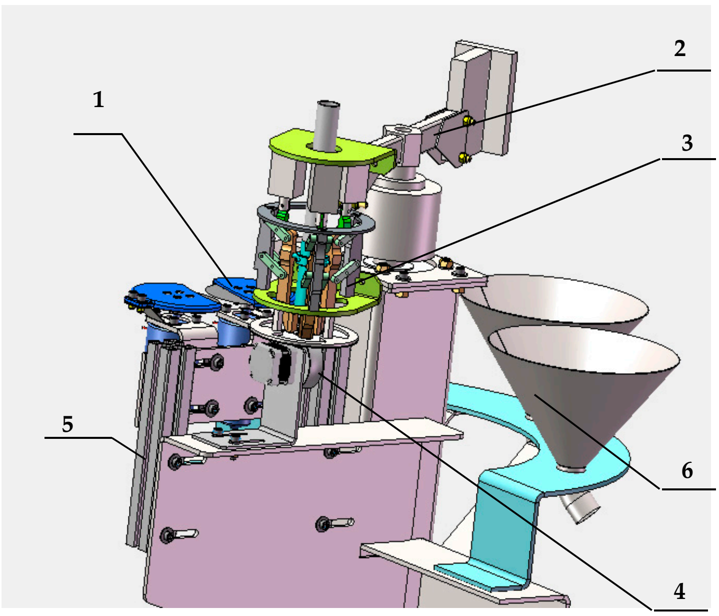


Figure 16. The virtual 3D model of the main unit of the automatic device for acorn scarification and assessment of mummification changes. (**1**) support stand; (**2**) gripper arm; (**3**) gripper; (**4**) positioner; (**5**) scarification unit; (**6**) acorn reception unit.

3.1.5. Results of the System Performance

The results obtained from the visual system designed to determine acorn length and orientation may be considered satisfactory in the context of its use for the control of the automatic scarification device. The applied seed orientation detection algorithm using the Harris detector was 90% accurate. This value was determined empirically on a sample of 88 seeds. The remaining seeds, missing from the full 100%, were the ones identified by the system as unrecognised, which means that the system is characterised by a lack of erroneous detection although in some cases automatic detection of orientation turned out to be impossible.

The length of acorns in the digital images was determined in pixels, while determination of the location of the cut required conversion of the size to millimetres. Scaling was performed in order to obtain the required size as a metric one; and on the basis of a set of 50 acorns sized from 24 to 37 mm the following conversion factor: f = 0.0744 mm/pix was adopted. Using this conversion factor, a large sample of acorns was measured using the vision system as well as traditionally (by use of a caliper). It was found that the average relative error of the visual measurement was 0.016% and its limit value did not exceed 3.6%. These results were considered satisfactory.

3.2. The Impact of Scarification on Seedling Quality

The aim of this part of the study was to determine the relationship between the mechanical scarification of common oak acorns (*Quercus robur* L.) and the quality of seedlings grown using the container method. In the 'ZAPORA' seed and nursery farm in the Bielsko Forest District, a field experiment was established: 800 items were selected out of yet to be sorted acorns, and divided into two groups: those intended for scarification (400 items) and those with no such treatment (400 items). Containers filled with substrate on the processing line and containing the seeds were placed in a tent covered with a double air bag; climate control and irrigation were controlled by a climatic computer according to a standard technological regime. The process of germination was recorded weekly (Figure 17). The control was discontinued after 11 weeks, when no further emergence was observed; and at the end of the growing season the breeding quality of the obtained seedlings was assessed.

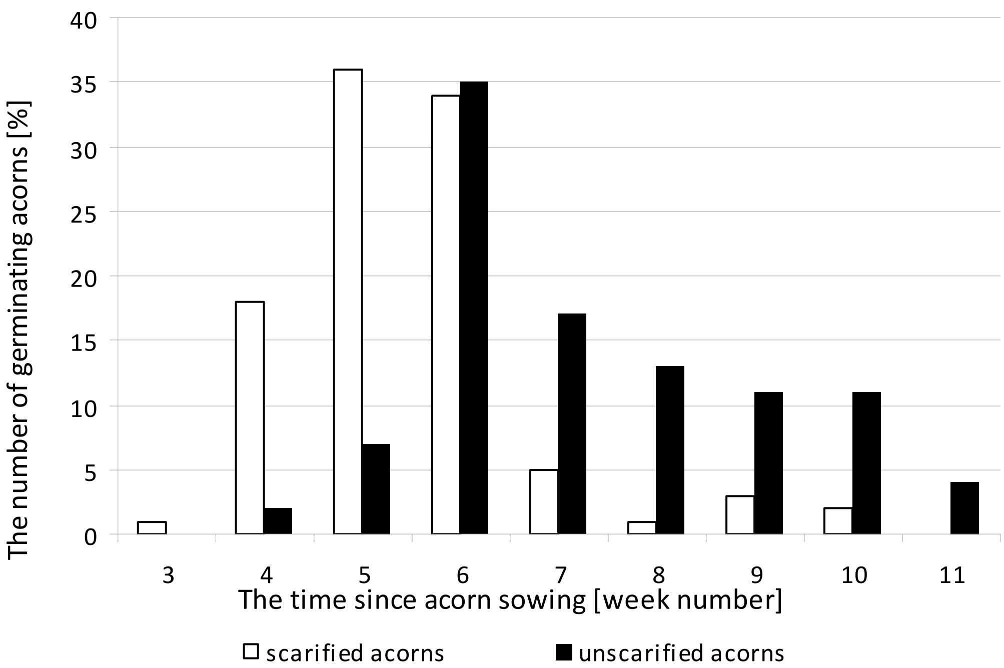


Figure 17. The quality of common oak seedlings.

An analysis was performed of the size of the assimilation apparatus of the seedlings, taking into account the pre-sowing method of acorn preparation. Leaf parameters were analysed using Winseedle (Regent Instruments Inc., Quebec, QC, Canada) software. For each seedling were determined were: the morphological characteristics and dry mass of the shoot, assimilation apparatus and root system, using a laboratory dryer (65 °C, 48 h) and an analytical balance. The results of the seedling quality assessment are provided in Tables 3 and 4 below.

The studies and analyses performed showed that the process of acorn scarification has a positive effect on later improvement of the uniformity and acceleration of seedling emergence. In the case of seeds subjected to scarification from 4 to 6 weeks after sowing, 83% of the acorns germinated. Among the seeds that had not undergone scarification, intensive germination started about 2 weeks later, and a similar percentage of seeds germinated only after 5 weeks. The time of oak seed germination has a significant influence on the morphological characteristics of seedlings. The seedlings grown from the scarified seeds had a similar height, a slightly smaller root neck diameter and smaller leaves while their dry mass was higher.

Table 3. The quality of common oak seedlings.

Seed Preparation Variant	Root Neck Diameter (mm)	Shoot Length (cm)	Root Length (cm)	Dry Mass of Shoot (g)	Dry Mass of Roots (g)
Scarified	6.36 ± 1.44	21.34 ± 7.01	17.24 ± 0.63	1.37 ± 0.75	5.22 ± 2.50
Unscarified	7.77 ± 1.29	20.91 ± 6.46	17.13 ± 1.45	1.12 ± 0.66	4.06 ± 2.13

Table 4. Parameters of the assimilation apparatus of common oak.

Seed Preparation Variant	Mean Leaf Area (cm^2)	Total Leaf Area (cm^2)	Leaf Length (cm)	Leaf Width (cm)	Dry Mass of Leaves (g)
Scarified	13.98 ± 0.20	43.50 ± 2.66	6.80 ± 0.05	3.18 ± 0.03	1.166 ± 0.037
Unscarified	15.19 ± 0.19	52.60 ± 2.41	7.09 ± 0.04	3.37 ± 0.02	0.985 ± 0.026

4. Discussion

The upper limb plays a very important role in people's everyday life. Thanks to it people are able to perform gripping and cognitive activities. The upper limb enables holding, touching, rotating and lifting objects. Due to the number and variety of tasks performed, the upper limb is particularly vulnerable to injury. For that reason, it is an object of research of both physicians and physiotherapists as well as biomechanics [30–32]. Łopatka et al. [33] have performed an analysis of the force of the hand grip, indicating the lack of correlation between the measured values and the anatomical build of the examined person. When analysing the average force of grip in the examined persons it was possible to state that the values of that force were influenced by the sex and age of the examined person. The results obtained may also be influenced by the physical fitness and the environment in which the persons live. It has been reported that a man's grip force can reach 300 N, while that of a woman is up to 170 N. A very important role is played by the biomechanical fitness of the upper limb in the case of manual scarification of common oak seeds. Manual scarification of oak seeds is a light job. The basic ergonomic defects of this job are: (1) the standing position (which is easily improved by changing to the sitting position) and (2) monotony (which cannot be eliminated). The scarification of 3–4 million seeds requires the involvement of about 20–30 people for about 1 month. Both the monotony of this work and the large number of workers needed for acorn scarification indicate that it is justified to replace that manual labour with automated work (a robot).

As demonstrated by the research, the process of scarification has a positive effect on the rate of germination and the equalisation of common oak emergence. The observed consequences of the removal of the distal part of acorns coincide with the observations made by other authors. Acorns with their distal part removed grew faster and their shoots were more equalised than in the case of unscarified acorns [20]. A similar dependence has been observed by Vallejo-Marini et al. [34] in their study of simulation of seed damage by rodents, performed on one of the tree species of the neotropical rainforest. Suszka [35] has also shown similar effects of the cutting off of 1/3 of the distal part of acorns. Ripe acorns require the access of water from the outside, penetrating the inside of the seed through possible cracks or slits in the shell, allowing activation of the embryonic root [36]. Due to the mechanical damage of the seed shell, it is easier for the embryo to receive water, and gas exchange is also easier. It is undisputable that the process of scarification damages and reduces the mass of the cotyledon; however, this treatment takes advantage of the natural ability of oak seeds to tolerate minor damage. Such damage may occur naturally: oak seeds are spread zoochorically, by rodents, squirrels and birds, which often results in partial acorn damage [12].

The study has shown that the entire germination period of acorns could be completed within 6 weeks after sowing as 90% of all shoots emerged during this period. Also Giertych and Suszka [20] in their article devoted to the consequences of removal of cotyledon parts in the oak seed, have observed that almost 6 weeks after sowing almost all the acorns emerged. According to Zajączkowski [37] the process of mechanical scarification as exemplified by black locust seeds may result in 90–95% germination. In the case of common oak seeds, the germination ability is ca. 20% higher as compared to seeds not subjected to that treatment. In the present study, the germination ability of acorns that had undergone scarification was 51%. However, if selection had been made on the basis of the mummification changes shown in the topography of the acorns and only the best acorns had been planted, the germination ability would have been increased to about 83%. This is similar to the results obtained by Giertych and Suszka [20], who, prior to sowing the scarified seeds, had rejected the damaged ones, thus obtaining the final germination rate of 83–88%.

The production of seedlings, especially in containers, requires the use of selected seed material of the highest germination capacity and characterised by equalisation of emergence. The process of mechanical scarification often accelerates the growth of the embryonic axis, thereby increasing seed germination and seedling growth. Another advantage of the container plant production is better use of space in the greenhouse. Cutting off the distal part of an acorn not only has a positive effect on seed germination but also allows for visual assessment of the health of the cotyledons and the entire acorns. By doing so we are able to reject disease-altered seeds before sowing, which also results in improved emergence and reduced economic losses. The seedlings obtained in this way have appropriate proportions between the root and the stem although they are slightly lower than those produced from undamaged acorns. On the other hand, a significant reduction in the growth of the stem in the first and second year follows the removal of a significant part of the cotyledon (removing 2/3 of the acorn on the side of the cupule). Thus, the best solution for the production of oak seedlings in container nurseries is to reduce the acorn mass by 1/5.

5. Conclusions

The intensive production of seedlings in the container system requires the use of selected seed material with the highest possible germination capacity, additionally characterised by the equalisation of the time of emergence. The application of mechanical scarification accelerates the growth of the embryonic axis, thereby increasing seed germination and seedling growth. A scarified seed is also classified either as healthy, i.e., potentially capable of producing a seedling, or as diseased. This assessment is issued by a person performing scarification, i.e., an expert. However, due to the scope and duration of the activities involved, manual scarification is a monotonous as well as physically and psychologically tiring process for the worker. Automating this process allows for effective replacement of human work.

The results obtained from the visual system designed to determine acorn length and orientation may be considered satisfactory in the context of its use for the control of the automatic scarification device. The applied seed orientation detection algorithm using the Harris detector was 90% accurate. This value was determined empirically on a sample of 88 seeds. The remaining seeds, missing from the full 100%, were the ones identified by the system as unrecognised, which means that the system is characterised by a lack of erroneous detection although in some cases automatic detection of orientation turned out to be impossible.

The studies and analyses performed have shown that the process of acorn scarification has a positive effect on later improvement of the uniformity and acceleration of seedling emergence. In the case of seeds subjected to scarification from 4 to 6 weeks after sowing, 83% of acorns germinated. Among the seeds that had not undergone scarification, intensive germination started about 2 weeks later, and a similar percentage of seeds germinated only after 5 weeks.

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