Paweł TYLEK[1], Jakub KLOCEK[2], Adam PIŁAT[3], Zdzisław KALINIEWICZ[4], Arthur I. NOVIKOV[5], Łukasz MATEUSIAK[1]

University of Agriculture in Krakow (1), Optister Krakow (2), AGH University of Science and Technology in Kraków (3), University of Warmia and Mazury in Olsztyn (4), Voronezh State University of Forestry and Technologies Named after GF Morozov (5)

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Assessment of the effectiveness of an autonomous device for pre-sowing scarification and sorting of acorns

Abstract. *The paper presents the model of a rotary autonomous scarifier, which cuts acorns with precision and sorts them based on an innovative optical resolution feature. The device is equipped with two optical systems, the first of which checks the spatial orientation resulting from the random feeding of acorns through the feeder, while the second one is responsible for controlling the health of the acorns. Seedlings grown from acorns were assessed for viability based on the measurement of electrical conductivity. As plant cells have a capacitive element, mainly constituted by cytoplasmic membranes, the value of the measured electrical conductivity is the sum of conductance and susceptance, and the obtained result is called admittance. The fundamental advantage of this method is the ability to determine the viability of seedlings using a single measurement.*

Streszczenie. *Przedstawiono model karuzelowego, autonomicznego skaryfikatora, który dokonuje precyzyjnego obcięcia żołędzi oraz sortuje je na podstawie innowacyjnej, optycznej cechy rozdzielczej. Urządzenie zostało wyposażone w dwa systemy optyczne, z których pierwszy sprawdza orientację przestrzenną, wynikającą z losowego podawania żołędzi przez podajnik, natomiast drugi odpowiada za kontrolowanie zdrowotności. Wyhodowane z żołędzi sadzonki poddano ocenie ocenie żywotności na podstawie pomiaru przewodnictwa elektrycznego. Ze względu na występowanie w komórkach roślinnych elementu pojemnościowego, jakimi są głównie błony cytoplazmatyczne, wartość mierzonego przewodnictwa elektrycznego jest sumą konduktancji i susceptancji a otrzymany wynik określamy mianem admitancji. Fundamentalną zaletą tej metody jest możliwość określenia żywotności sadzonek przy wykorzystaniu tylko jednego pomiaru (**Ocena efektywności działania autonomicznego urządzenia do przedsiewnej skaryfikacji i sortowania żołędzi**)*

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Keywords: acorns, scarification, image analysis, automation, admittance
Słowa kluczowe: żołędzie, skaryfikacja, analiza obrazu, automatyzacja, admitancja

Introduction

The scarification procedure consists in damaging the seed coat in order to initiate the seed germination phase [1]. In the case of an acorn, mechanical scarification is executed by cutting off approximately 1/5 of its length on the side of the hilum (Fig. 1). Currently, approximately 6 million acorns are sown annually in container nurseries in Poland. The number of acorns subjected to scarification must be significantly higher, because a significant number of them (even over 50%) may be damaged by insects, rodents or fungi [2, 3]. The result of scarification is the acceleration and uniformity of emergence. This is important because the planting material, which is highly diversified morphologically, is not suitable for forest regeneration or afforestation with automatic and robotic systems. The added value of scarification is the ability to separate seeds based on visually determined mummification changes. It is possible to increase the field germination capacity by approximately 30% by pre-sowing rejection of necrotic seeds. The duration of the manual work cycle is approximately 3 s, so the scarification of just 1 million seeds requires over 100 working days [4].

Fig. 1. Manual scarification and sorting of acorns

Modern nursery production technologies require high-quality seeds so that each seed can produce a seedling with specific morphological parameters. The highest germination capacity is expected from seeds intended for sowing in container nurseries, where only one seed should be sown in one container cell, and produce a healthy seedling. It should be borne in mind that the germination capacity of acorns depends, among others, on the size of the seeds and the age of the stand from which they were obtained [5, 6]. However, the largest problem is the need to eliminate seeds damaged by insects and fungi.

Sorting the seed material by applying the classic separation features such as mass, density, size, shape, friction, elasticity or aerodynamic properties does not provide the expected effectiveness in the case of oak seeds [7-9]. Hence the interest in other seed separation features, e.g. optical ones. So far, attempts have been made to base seed sorting on the color of the seed coat [10, 11] or on near infrared (NIR) analysis [12, 13]. However, acorns subjected to scarification commonly undergo organoleptic assessment of the topography of mummification changes visible on the cotyledons [2, 14]. Automation of seed separation processes by using computer image recognition techniques and elimination of the subjective perception of seed health by nursery employees make the optical properties of scarified acorns an innovative separation feature with high efficiency and great application potential.

Another problem in the production of forest breeding material is the assessment of the quality and viability of seedlings. Their quality is usually determined on the basis of biometric features, i.e. the height of the above-ground part, the diameter at the root collar and the length of skeletal roots and architecture of root systems [15, 16]. However, these measurements are tedious and do not always correlate with seed viability, hence the need to develop a quick and effective method. Currently, objective methods of viability assessment are being sought, i.e. ones that would measure electrical parameters. When examining root systems, it is possible to measure electrical impedance or capacitance [17, 18]. When assessing the above-ground part of a seedling, admittance measurements are the most promising [19].

The scarifier operation principle

The central assembly of the robot is a rotating arm with a gripper (Fig. 2). The device has an acorn container with a vibrating feeder, the operation of which ensures that the seeds are transported along a spiral chute to a place where they are individually dispensed to the length and orientation detection unit. Above the conveyor there is a camera which records the image of an acorn during transport (Fig. 3). A specialized computer vision system identifies its position and measures its length [20, 21]. If the acorn is positioned in the wrong direction (with the sprout at the front, instead of the stalk), it is returned through the return branch to the feeder. Seeds positioned correctly along the main track are moved to the length detection system; and it is this parameter that defines the subsequent determination of which part of the acorn will be cut. The acorn then falls by gravity through a tunnel integrated with the rotating arm into the gripper mounted at its end.

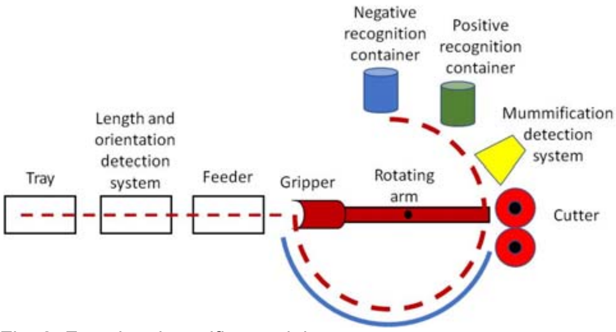

Fig. 2. Functional scarifier model

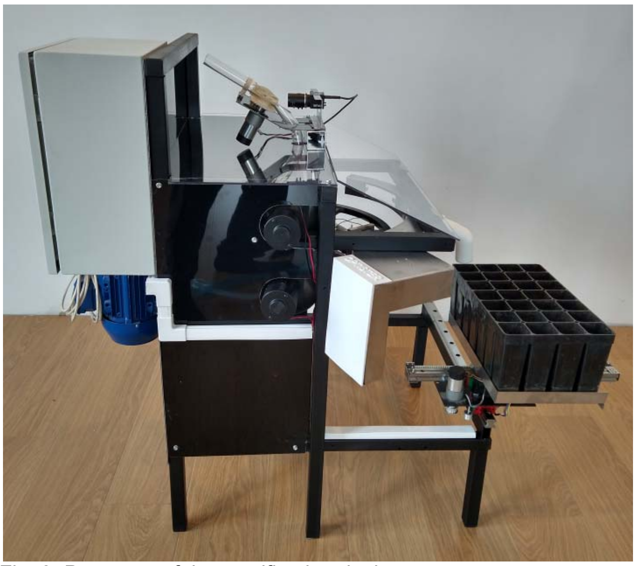
Fig. 3. Prototype of the scarification device

During the rotational movement of the arm, an acorn is pressed by centrifugal force against the positioning band with a fixed curvature in such a way as to obtain a smooth change of the difference in the distance between the arc of the band and the axis of rotation of the arm. The pressing time corresponds to the positioning angle, which is a function of acorn length, and then, on a signal from the control system, the gripper closes. The gripper has a fixed bed and a movable cramp, equipped with a set of coils and permanent magnets. Changing the polarity of the coil power supply changes the direction of movement of the cramp. In the next stage of rotation of the arm, an acorn reaches the rotating disc knives of the scarifier, where it is cut (Fig. 4).

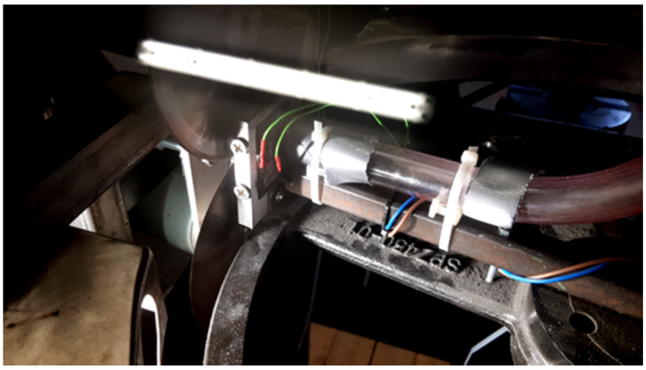
Fig. 4. Cutting unit of the scarification device

The exposed part of an acorn is assessed for health using another vision system, and the acorn is classified into one of two categories: healthy or unsound seeds (Fig. 5). It is also possible to distinguish a category of unrecognized seeds [22, 23]. Further on, acorns are released into appropriate containers. The moment of releasing the gripper clamp depends on the detection result, the gripper's rotational speed, its dynamics and the location of the receiving containers. Once an acorn is released, the arm continues its movement and is ready to receive the next one. The device has an integrated controller and a control panel, and is mobile.

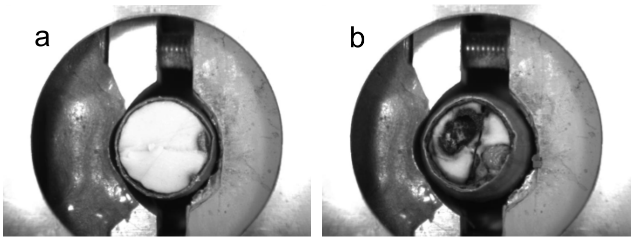

Fig. 5. Gripper in the camera's field of view with sample cross-sections of acorns after scarification: a – healthy seed, b – unsound (mummified) seed

Assessment of scarification effectiveness

In the present research, seeds were separated using the proposed algorithms for analyzing images of necroses on scarified acorns, with 4 degrees of intensification of this process adopted. The seedlings grown from those seeds were compared with seedlings produced using the classic method, i.e. grown from the seeds scarified and sorted manually. The quality and viability of seedlings were determined based on biometric features, i.e. the height of the above-ground part and the diameter at the root collar. These parameters were supplemented by measuring the electrical conductivity of the seedling shoot. As plant cells have a capacitive element which consists mainly of cytoplasmic membranes, the value of the measured electrical conductivity is the sum of conductance and susceptance, and the obtained result is called admittance [19]. The flow of electric current is the result of an electric field penetrating the selected medium. The components of the medium, such as ions and electrons, are then stimulated to move. A device enabling the measurement of admittance in plants is a conductivity meter operating under constant, low frequency current (80 Hz) and voltage (0.2 V). In the present research, the CX-461 universal instrument was used, measuring this parameter with an accuracy of 0.001 µS cm^{-1} (Fig. 6).

The measurement takes about 3 seconds and is performed with the use of an electrode with nickel-plated needles, inserted at mid-length of the last increment of each seedling. The meter has an internal measurement memory, which facilitates data archivization. The measurement results of selected seedling parameters are summarized in Table 1.

Fig. 6. Measurement of admittance of the shoots of pedunculate oak seedlings using the Elmetron CX-461 universal device

Tab. 1. Biometric features and viability of seedlings depending on scarification technology: *E* – separation effectiveness, *Ø* – root collar diameter, *L* – shoot length, *A* – admittance

Method and intensity of scarification [%]	*E* [%]	*Ø* [mm]	*L* [cm]	*A* [μS·cm^{-1}]
Manual approx. 25	96.2	5.25 ±1.77	26.40 ±10.78	11.55 ±2.16
Automatic 15	83.0	7/08 ±1.31	27.54 ±7.19	13.18 ±1.96
Automatic 20	90.1	6/09 ±1.44	26.21 ±8.22	12/04 ±1.91
Automatic 25	94.3	6/05 ±2/08	21.60 ±8.16	12.36 ±2.75
Automatic 30	98.1	5.79 ±2.10	22.17 ±8.24	12.68 ±2.69

Based on pilot studies, it can be concluded that the effectiveness of seed separation done using a robot is comparable to the seed separation performed by employees, taking into account the similar scarification intensity. The obtained seedlings showed better biometric parameters: a larger root collar diameter with a slightly lower length of the above-ground part. A similar level of admittance was recorded for all experimental variants. Moreover, it can be noticed that more intensive scarification results in greater diversity of the quality characteristics of the planting material.

Discussion and summing up

Scarification with the use of pruners requires the employment of more than 10 people in each nursery producing seedlings. The ergonomic burden of that labor consists in the repetitive movement of the arms and hands several thousand times a day in the cycle: picking up an acorn, positioning it in the appropriate direction, cutting off the distal part, visually assessing its health, putting it in an appropriate container [4]. Previous attempts to mechanize and automate these processes ended with the proposal of two solutions that did not gain user approval and did not go beyond test models. The prototype device (2 items produced) enabling the mechanization of the scarification process is a cutter manufactured by Gidpol. The employees collect acorns manually and place them in a carousel feeder, which moves them to the operation area of the knife that cuts off the stem part. The feeder has handles adapted to hold acorns of three sizes. The operator must therefore not only place the seed in the correct direction in the holder, but also select the holder. The cutter does not ensure a constant proportion of the length of the part being cut off in relation to the size of the seed. Another disadvantage of that solution is the inability to directly assess the health status of the seeds. This treatment must be carried out later, as a separate technological activity. The Jarocin Forest District is testing a machine called Quercomat Q1 (1 item has been constructed), manufactured by EMDE Zakład Elektroniczny. The operator feeds each acorn with its correct side positioned at the front into the suction cups placed on the rotating feeder. After scarification, the carousel with seeds moves to the operating zone of a camera which records the view of the scarified acorns in a given work cycle. In the next cycle, sorting is performed based on the image analysis result. The pneumatic gripper system fails in the case of acorns with wrinkled or cracked seed coats. Moreover, for a given batch of seeds, the length of the cut-off part is independent of the acorn size, which leads to differences in the intensity of the treatment [24].

The robot designed by us has no equivalents among machines used in forest management: it is an absolute technological novelty on the global market. It enables replacing the work of 15 people with the employment of 3 people supervising the operation of the machine in a three-shift system. The proposed solution is a significantly simplified version of the device which, as a functional model, was designed, constructed and tested as part of the project entitled “The functional model of an automated device with a vision system for scarification and vitality assessment of acorns bason the basis of automatic recognition of the topography of mummification changes” [4, 20, 24]. The uniqueness of the device on the global scale has been confirmed by the granting of patent number Pat.243236.

Compared to its original, the solution presented here has the following characteristics: (1) mechatronic systems have been significantly simplified, (2) electric-pneumatic drives have been replaced with electric ones, (3) dimensions and weight have been reduced (approx. three times), (4) effectiveness has been increased (almost 10 times), (5) operating procedures have been simplified. Important innovative solutions include: (1) fully autonomous operation, (2) recognition of the direction of feeding the acorns, (3) length detection, which allows for constant intensification of scarification, (4) use of the topography of mummification changes as a separation feature, (5) auto-diagnostics, (6) auto-calibration of sensors and cameras, (7) self-learning and improvement of the detection process, (8) an option of connecting an additional device for sowing in containers.

The tangible benefits of using the scarifier in practice are: (1) improving the quality of the seed material; (2) meeting agrotechnological deadlines; (3) elimination of manual labor (in Poland alone, burdensome manual scarification generates the enormous number of 7,500 man-days); (4) shortening the seedling breeding period by 6 weeks (performing the sowing in two agrotechnological periods and doubling the production); (5) increasing the breeding success (increase by 20-40%; in the case of a single nursery, increasing the value of annual production by PLN 0.5-1.0 million); (6) inclusion in the concept of

Agriculture 4.0 in the field of development of autonomous systems, long awaited due to the lack of people on the market willing to perform this type of work.

Preliminary analyses indicate a greater viability of seedlings derived from seeds scarified and sorted by the automated device. Higher intensity of scarification increases the effectiveness of acorn separation, but reduces the robustness of seedlings, as determined by biometric parameters [2]. Separation based on the observation of the acorn cross-section may cause some losses. This is due to the imperfect assessment of the distribution of necrotic foci over the seed cross-section. The observer has insight only into the cotyledon zone. Therefore, acorns with partially damaged cotyledons may be classified by the observer as unsound even though, in fact, as just partly unsound seeds, they do have some germination potential. Moreover, acorns without necrotic changes in the cotyledon area can be classified as healthy, even though the mummification of the invisible embryonic root should disqualify them from sowing in the nursery [21, 24].

The advantages of assessing seedlings using admittance measurement include the ability to perform measurements in field conditions, the speed, as well as only minimal interference in seedling tissues. The fundamental advantage of this method is the ability to determine the viability of seedlings using only one measurement.

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***Authors**: dr hab. inż. Paweł Tylek, prof. UR, University of Agriculture in Krakow, Faculty of Forestry, Department of Forest Utilization Engineering and Forest Techniques, al. 29 Listopada 46, 31-425 Kraków; E-mail: pawel.tylek@urk.edu.pl; dr hab. inż. Adam Piłat, prof. uczelni, E-mail: ap@agh.edu.pl; dr inż. Jakub Klocek, E-mail: optister.krakow@gmail.com; dr hab. inż. Zdzisław Kaliniewicz, prof. UWM, E-mail: zdzislaw.kaliniewicz@uwm.edu.pl; associate professor Arthur I. Novikov, E-mail: arthur.novikov@vglta.vrn.ru; mgr inż. Łukasz Mateusiak, E-mail: lukasz.mateusiak@urk.edu.pl*

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