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VIS-NIR wave spectrometric features of acorns (*Quercus robur* L.) for machine grading

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Abstract. The study is intended for engineers and small-scale forestry owners because it offers a simple solution for acorns quality improvement by machine grading before sowing. Visible diffuse reflectance spectra of single whole acorns (*Quercus robur* L.), damaged acorns, acorns pericarp, whole and damaged acorn seeds were scanned with spectrometer USB 4000 (Ocean Optics Inc., USA) from 450 to 900 nm at 1 nm intervals. Near infrared reflectance spectra of single acorns material were scanned with spectrometer NirQuest512 (Ocean Optics Inc., USA) from 900 to 2100 nm at 1 nm intervals. English oak acorns cannot be divided from damaged acorns and acorns pericarp in the visible wavelength range. Hard-to-release damaged acorns with shell cracks are eliminated in the NIR-reflectance at a wavelength range from 1400 to 1500 nm or from 1900 to 2000 nm. After the elimination of damaged acorns, good whole acorns can be grading from the acorns rotten seed and acorns pericarp (only one the inner side of a shell) at a wavelength range from 1600 to 1700 nm. The results of this study are limited to these specific samples and cannot be interpreted for acorns of all Quercus species.

1. Introduction

Natural regeneration of oak forests [1] from seed [2] on a large area is difficult because among acorns have high mass and density. Natural regeneration from seed "*is a more intricate pathway with several potential bottlenecks (e.g. seed and micro-sites availability, predation, seedling-saplings conflicts)* [2]" Animals easily destroy the acorn pericarp [3] when eating and the seed is digested, so the greatest influence on the acorns distribution have a birds. However, for modern regeneration is not enough. Need the humans help and artificial regeneration [4] "*by seeding or planting (traditionally, both methods have been recommended), provided that acorn predators are controlled* [2]".

Currently, the collection of acorns is done manually "*either in nets or on the cleared ground under the trees* [5]". Traditionally, it is believed that "*signs of bad seeds are pale pericarps or very light acorns* [6]". Then the acorns material is transported to the seed centers. It is costly, including increased fuel consumption due to the use of trucks, additional damage to acorns during transportation and loss of time. In the seed centers, acorns in most cases floated, dried and sorted, using manual labor and organoleptic method. These further increases the processing time.

Since the volume of acorn harvesting in some small farms is measured in tons, the use of optical methods in the preparation of acorns has significantly reduced these costs. Non-destructive quality control of forest seeds [7,8] before sowing and storage it is an important factor for contemporary reforestation [9]. According to author, “*also an important methodical factor specific to forestry is the portable design of optoelectronic devices which can used on field and low costs for the implementation* [10]”.

For forest seeds including acorns visual (VIS) and near infrared (NIR) spectrometric analysis is a tool that determines their viability [11–15], provenance [16] and morphological composition [17,18].

Studies of seed coat in the near infrared transmittance spectra have proved the possibility of seeds optical grading [8]. Moreover, the oak seeds are inside the pericarp, therefore, may have spectrometric properties different from the whole acorn. However, all researchers suggest the possibility of using optical radiation in practice, but do not give specific recommendations on specific technological parameters for the design of grading devices.

The forest seeds express analyzer development, working on the basis of spectrometric criteria in a wide range of wavelengths from visible to near infrared, will solve the problem of the quality of forest reproductive material (FRM) only partially, since it is necessary not only to determine the quality indicators of the seeds themselves, but also to ensure the quality of seedlings at the juvenile stage of ontogenesis [19]. Therefore, it is necessary to design and plan [20,21] a line of mobile devices for processing [22] and sowing [23,24] viable seeds, taking into account modern trends in FRM technology.

To implement the algorithm of machine grading and design of devices that can qualitatively separate whole acorns from damaged ones, it is necessary to accumulate data on the spectrometric properties of acorns and their parts.

This study answers the following question. Is it possible to grading good whole acorns of *Quercus robur* L. from acorns with cracked shells, damaged acorn seeds and pericarps in a visible (VIS) or near infrared (NIR) reflectance wave range?

2. Materials and methods

Acorns of *Quercus robur* L. were collected from ground, in natural forest in autumn of 2018, located in the Pavlovsky district of the Voronezh region, Russian Federation (Latitude 50.462169; Longitude 40.096446, Altitude 83 m asl). Acorns material transported in bulk used the back of the car. Original seedlot was formed using the standard procedures at the Voronezh containerized forest nursery, Russian Federation (Latitude 51.567094; Longitude 39.243006, Altitude 105 m asl).

From ten places of the upper, middle and lower layers of the initial material of acorns, 30 recesses were made in a wooden box so that the total weight was 15 kg. The box for controlling the mass of acorns was installed on a scale. Then manually mixed the contents of the box and selected from it in a container three recesses weighing 1.5 kg each, respectively, from the upper, middle and lower parts. The weight of the recesses was controlled on scales. These notches were then mixed on a flat surface. The average sample weighing 1.5 kg for the study was obtained by cruciform division according to the methodology set out in the state standard [25].

From average sample, we selected five acorns material classes in using an organoleptic test: whole acorns (W), damaged acorns (with shell cracks) (D), acorns pericarp (P), whole acorn seeds (WS) and damaged acorn seeds (DS). Additionally, these acorns material were classified in the Munsell color system (table 1) using the digital camera Canon Digital IXUS 100 IS 12.1 MPix (Canon Inc., Tokyo, Japan) for obtaining images and for image processing Digital Color Guide android-software (DIC Corp., Tokyo, Japan).

A total of 100 English oak (*Quercus robur* L.) samples from Whole acorns (n = 40), Damaged acorns (with shell cracks, n = 15), Acorns pericarp (n = 15), Whole acorn seeds (n = 15) and Damaged acorn seeds (n = 15) were analyzed for their spectrometric parameters in the visible (VIS) and near infrared (NIR) wavelength ranges.

Visible diffuse reflectance spectra of single samples from each material classes were scanned with spectrometer USB 4000 (Ocean Optics Inc., USA) from 450 to 900 nm at 1 nm intervals. Near infrared reflectance spectra of single acorns material were scanned with spectrometer NirQuest512 (Ocean Optics Inc., USA) from 900 to 2100 nm at 1 nm intervals.

The optical radiation reflected from the seed passes through the integrating sphere FOIS-1 (Ocean Optics Inc., USA), the fiber-optic cable P400-2-VIS-NIR (Ocean Optics Inc., USA) to the entrance slit of the spectrometer. At the output of the optical system, a voltage proportional to the light intensity was generated using a CCD line. The reflectance VIS and NIR spectra as a dependence of the reflected radiation intensity R (in percentage) from wavelength λ (in nanometers) was obtained by analog-digital conversion. The results were processed on a personal computer using Spectra Suite application software.

3. Results and discussion

Gradually there is a transition from a verbal description of the color to its numerical characteristics, which allows us to assess the role of certain pigments in the color of seeds. Organoleptic method of determining color is quite subjective and depends on the perception and characteristics of the human eye [10,26]. This should describe the color of the acorns with the help of any optical system. In forestry, the oldest optical system is the most common Munsell [27]. Using a digital camera and software, we will translate the color parameters of the samples into the Munsell system (table 1). The averaged parameters of samples 1 and 4, as well as 2 and 3 coincide with each other. Consequently, the use of the visual method for the separation of these particles will is problematic. To confirm the technological possibility of acorns separation by spectrometric, we will carry out measurements of samples from W, D, P, WS and DS-material acorn groups (see table 1).

Table 1. Color classes of *Quercus robur* L. acorn material used in the study.

Acorn material group	Color classes of Munsell system
1 – Whole acorns (W)	5.8 YR 3.2/4.8
2 – Damaged acorns (with shell cracks) (D)	0.8 YR 3.1/7.2
3 – Acorns pericarp (P)	0.8 YR 3.1/7.2
4 - Whole acorn seeds (WS)	5.8 YR 3.2/4.8
5 – Damaged acorn seeds (DS)	9.1 YR 3.1/3.1

Figure 1 shows that used organoleptic test can be classified in five specific groups of English oak acorns. These groups are often found in the initial bulk before the acorns are divided into original seedlots. Groups are classified as whole acorns (figure 1a), damaged acorns with shell cracks (figure 1b), damaged acorn seeds (figure 1c), acorns pericarp (figure 1d), and whole acorn seeds (figure 1e).

a) b) c) d) e)

Figure 1. Representative selected samples for the organoleptic test in W (a), D (b) DS (c), P (d) and WS-material (e) groups.

Figure 2 illustrates the VIS diffuse reflectance spectra of all acorn groups. Since the outer side of the acorn pericarp has similar color parameters with the whole acorn in the Munsell system, the spectrum of the shell was measured separately for the inner side. Despite the absence of a clear distinction of spectral lines for each group, in the wavelength range after 750 nm there are two characteristic areas between whole acorn seeds and undesirable impurities.

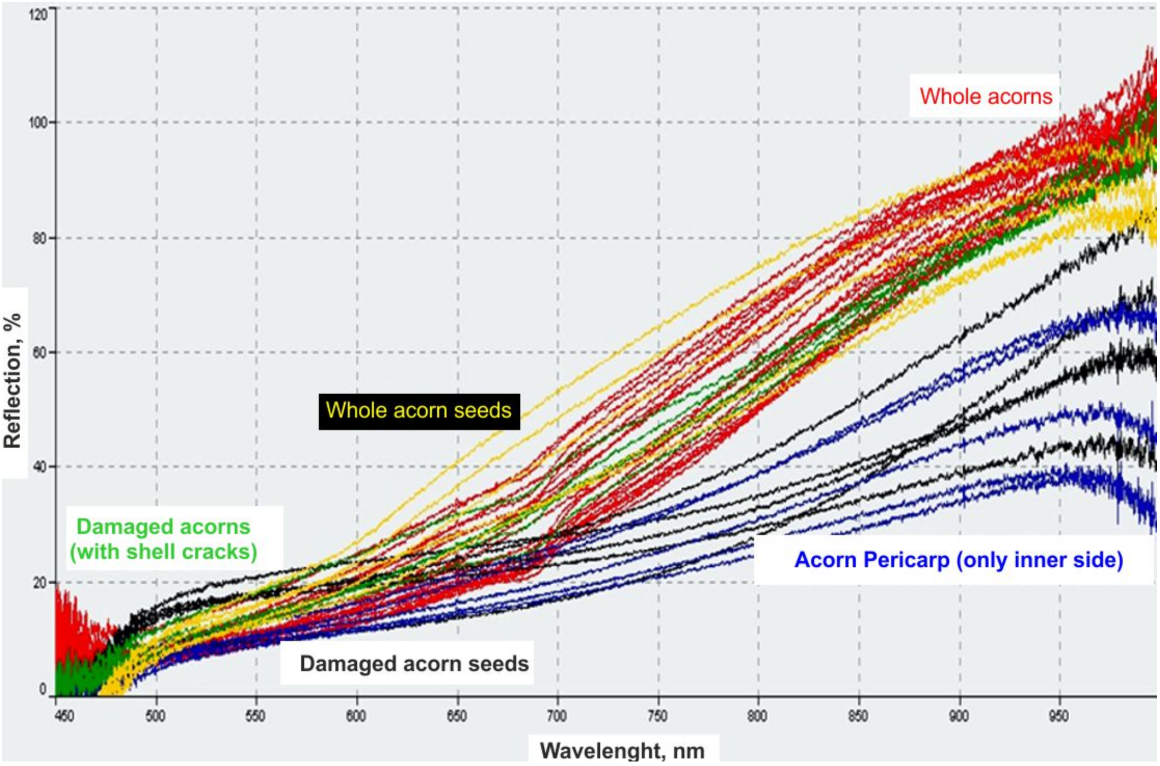

Figure 2. Diffuse reflection VIS-spectra samples of *Quercus robur* L. acorns.

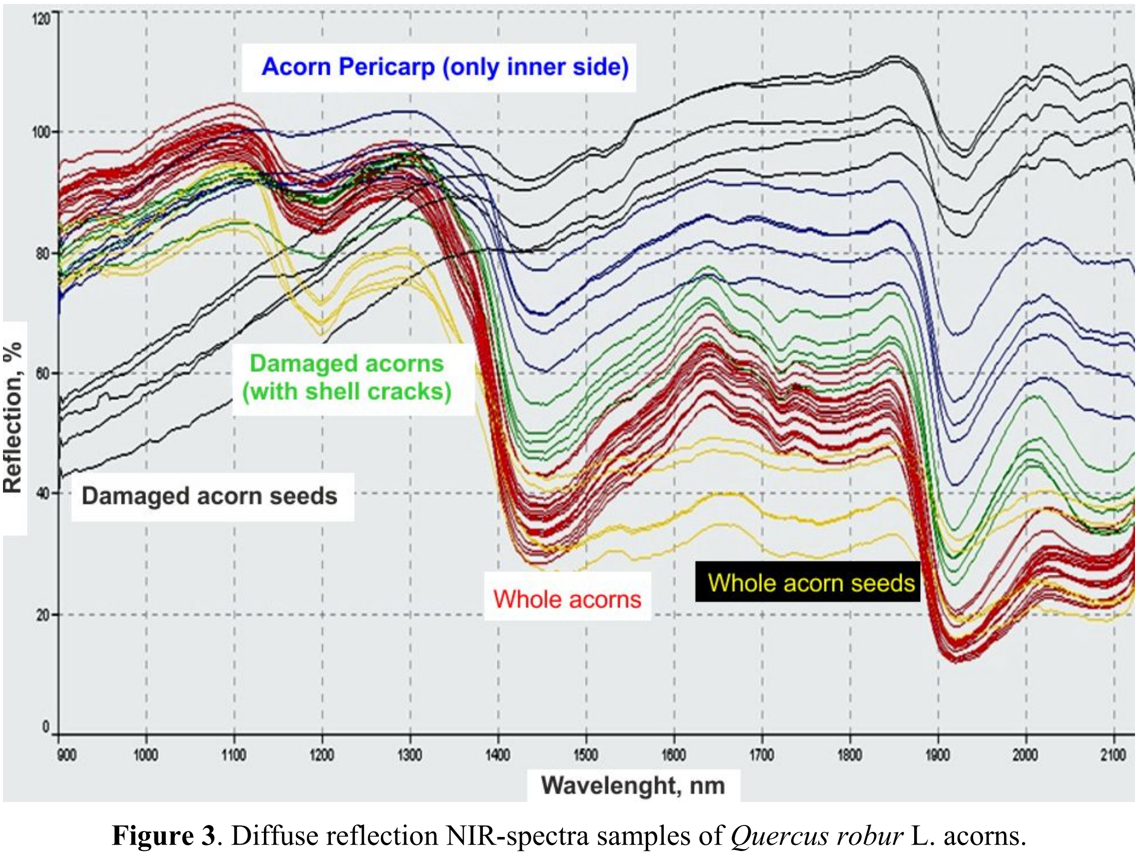

Figure 3. Diffuse reflection NIR-spectra samples of *Quercus robur* L. acorns.

It is assumed that at a wavelength of 800 nm, the mixture can be pre-cleaned from the shell and rotten seeds at a reflection degree of 25 to 45 %. However, in one technological transition, it will not be possible to divide the mixture into five components, which will increase the likelihood of repeated damage to acorns. Therefore, it is possible to recommend the use of the visible wavelength range in the design of the optoelectronic unit of the rapid sorter for oak seeds only in the case of incommensurable costs for the more expensive option with infrared rays.

Figure 3 illustrates the NIR reflectance spectra of all acorn groups. The difficulty of grading is acorns with shell cracks, but you can try to implement this task in the NIR reflectance at a wavelength range from 1400 to 1500 nm or 1900 to 2000 nm. Also in this case it is possible to additionally apply the mechanism of scarified acorns recognition described by Jabłoński et al. [15]. Whole acorn seeds can also be removed in the NIR reflectance at a wavelength from 1200 nm. After the elimination of acorn with cracks, good whole acorns can be grading from the acorns rotten nuclei and acorns pericarp (only one that does not match the color of the whole acorn, that is, the inner side of coat) in the NIR reflectance at a wavelength range from 1600 to 1700 nm.

However, there is an evidence of bimodal color [28] in forest seeds, so the results of the study can limited to this specific samples collected in Pavlovsk district of Voronezh region in Russia and cannot be interpreted for acorns of all *Quercus* species. Therefore, it is necessary to systematize and collect data for acorns collected from different provenances.

4. Conclusion

When designing the response frequencies of the photodetectors for machine grading of acorns, the following should be considered. English oak whole acorns (W) cannot be graded from damaged acorns (D) in the VIS reflectance wavelength range. In the NIR reflectance wavelength range it is necessary to set two frequencies – 1650 and 2000 nm. At 1650 nm it is possible to eliminate of whole acorn seeds, then at 2000 nm to grade the remaining groups of acorn material. In the future, it is necessary to conduct experiments to study the transmission spectra of acorn material using the Fourier transform.

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