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# An Investigation of Automatic Treatment of Seeds with Low Power Laser Beam

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**Original scientific paper**

The paper describes two successive sets of experiments of low-power diode laser treatment of corn kernels and wheat seeds. First experiment was conducted by use of laser beam for excessive moisture removing from corn kernels. Second experiment was conducted to determine influence of low power laser beam on mycotic population on wheat seeds. For proper doses indication seeds were artificially infected with various fungi, such as Penicillium, Fusarium, Alternaria, etc. in two intensities (high, low). The experiment was planned to establish the effect of laser treatment as compared to chemical treatment on sprouting efficiency, defined as percentage of total kernels that sprout after a specific incubation time, and on fungus survival, expressed as level of infection. An experimental conveyor belt system was build to expose the kernels / seeds to laser light in the latter case. Laser treatment was to some extent effective in increasing sprout efficiency and reducing fungus survival, although less effective in these preliminary experiments than fungicide treatment. This paper proposes an automatic set-up for laser beam treatment as an environmentally safe alternative to chemical treatment of various cultivars of seed.

**Key words:** moisture, kernels, wheat, corn, fungi, infestation, laser, preprocessing, ecology

## 1 INTRODUCTION

Natural systems are not easily manageable. Operational state and state estimation include their temporality as a basic ontological problem [1]. Variables and their interrelations define a state situation. In this sense there are several indicators that can be used for fast estimation and monitoring of the natural system state. The main objective of the indicators is to give a concrete and synthetic information easily recognizable by experts and laymen [2]. In our case of investigating automation possibility of grain treatment, the seed adaptation to external light pathways has been studied. Light pathways are very important for plants and seeds as well [4]. Seed energy and sensitivity to fungi infection have been chosen as control variable in the treatment process.

Fungi metabolism can influence surface layer of a grain (seed/kernel) while fungi feed on starch (endosperm) and cellulose damaging the whole grain.

By damaging the surface layer (pericarp), grain kernels/seeds can significantly lose moisture content necessary to maintain sprouting. Fungi metabolism can damage embryo, too. Basic structure of a wheat seed is given in Fig.1. It consists of embryo, endosperm, and two cover layers protected with pericarp.

Fungicides as chemical treatment are usually applied in order to stop the growth of fungi and to remove them from the seed surface. The experiments have indicated that seed treatment with low-power visible wavelength laser beam can significantly reduce seed-born fungi from the seed surface without damaging the seeds and resulting in the increased seeds sprouting [5]. It indicated also that low power laser beam can be used for general

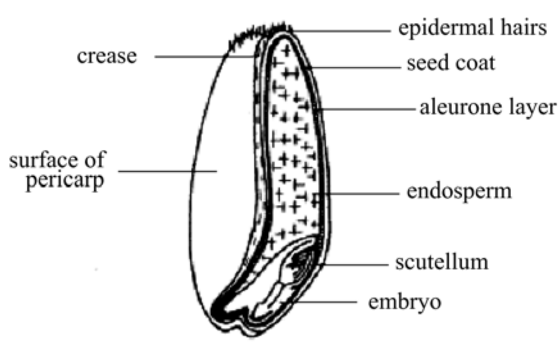



*Fig. 1 Basic structure of a wheat seed,* [5]

kernels/seeds preprocessing such as for removing excess moisture from the grain kernels/seeds at the harvest time [4]. However, kernels/seeds exposure to a higher power laser beam can cause severe destructive damage to the kernels/seeds and to the embryo as well. High power laser beam exposure can remove too much moisture from kernels/seeds and decrease kernels/seeds sprouting ability. Nevertheless high level of grain sprouting percentage is important in sowing stage resulting in possible higher crop (yield) later on.

It was necessary to investigate the balance between laser power, beam focusing, grain speed and biological effect. When a focused is used the laser beam source directs a spot on the surface of the seed. Glaze (enamel) coating of the corn kernel disperses laser beam all over the surface of the kernel, Fig. 2. Laser beam is scattered throughout the whole kernel rather than being restricted to the spot where the laser beam is making its impact [5].

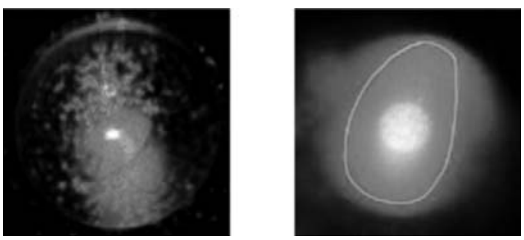


*Fig. 2 Laser beam and kernel interaction – light and intensity scattering (left – wheat grain illuminated by laser beam; right – close up view with emphasized boundary of the grain)*

Wheat seed does not scatter laser light in the same way as corn kernel because it lacks glaze coating. The investigation was thus directed to determination of complete set-up for grain treatment with laser beam including various effects of the beam-kernel/seed interaction.

## 2 REMOVING EXCESS MOISTURE WITH LASER BEAM

Grain drying process is performed after harvest or at the storage site silo in order to reduce the moisture content as low as possible. Further drying is performed during internal grain transportation among storage places. The stable value of moisture content is 14 % for corn kernel at silo. Data on stable moisture content differ from about 8 % to 14 % for different seeds. Not properly dried grain kernel/seeds is perishable, tends to overheat in silo and looses basic food qualities and its capability for sprouting because of biochemical processes induced by higher moisture content and higher grain temperatures.

Cost of grain processing includes equipment amortization, energy consumption, and labour work. Depending on the type of processing further cost can be expected in quality decrease such as grain mechanical damage, using of chemicals, grain degradation. Benefits include grain preservation, premium for quality, premium for non-using of chemicals, and energy savings. Best energy saving can be made in the pre processing phase. Pre processing can be done with dry hot air (110 °C or 130 °C) and very rarely with IR waves [10]. Better nutritional effects, higher germination and change of structure have been observed as well while processing wheat seeds with IR.

Basic corn kernels structure is given in Fig. 3. It consists of embrion, endosperm, rest of cover and nucleus and it is protected with pericarp.

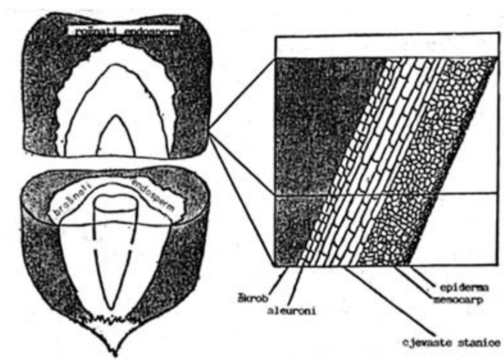



*Fig. 3 Basic structure of the corn kernel* [8]

Pericarp covers corn kernel. It consists of 10–12 cell layers with pigments. Between pericarp and outer layer of endosperm there is a thin membrane that protects the kernel, Fig. 4. Endosperm has two structures, horny endosperm and floury endosperm. Horny endosperm is heavier and more permissive, while floury endosperm is softer, crisper and relatively more opaque. Beneath the epiderm there is mesocarp, six layers of tubular cells and two layers of aleurons, Fig. 4.

The interaction between laser beam and grain (seed/kernel) structure depends on the applied wavelength, on type of the seeds/kernels and on the moisture content in seeds/kernels. Investigation of the impact of visible light on wheat seed has shown different features of floury and horny endosperm to this type of treatment. Floury endosperm of wheat seeds shows no absorption of near IR radiation with high scattering index be-

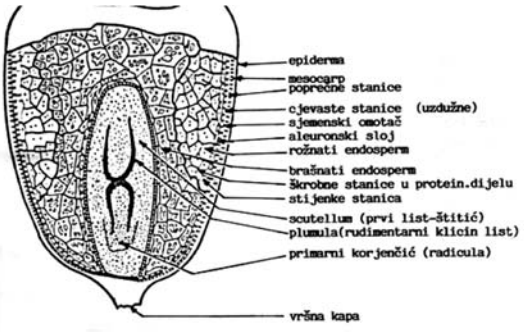
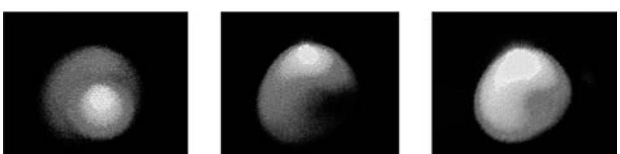



*Fig. 4 Detailed structure of the corn kernel* [8]

tween 0.97 and 0.99 and respective horny endosperm shows low scattering index between 0.57 and 0.70 [9].

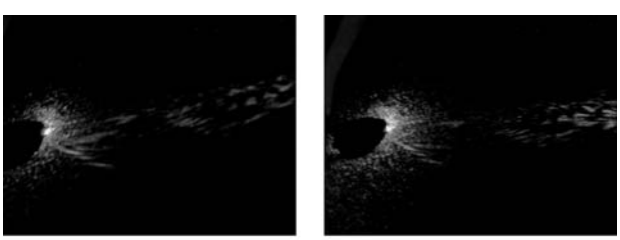
Drying intensity of the floury endosperm with low moisture content is very small. Experiments with near IR radiation for drying purposes have shown that wheat seeds absorbs enough energy in a few seconds in order to transform this energy to grain heating for release of enough moisture with further ventilation [9]. There were no particular studies involving laser beam and corn kernels interaction for drying purposes. Heating of the wheat seeds to temperatures between 60 °C and 90 °C has caused no visible destruction in hot air drying procedures.

The impact of focused laser beam on corn kernels surface is given in Fig. 5 as a series of photographs taken from kernels reflected light on black paper background.



a) b) c)

*Fig. 5 Laser beam and corn kernels structure interactions*



a) b)

*Fig. 6 Diffracted and reflected laser beam from aluminium edge and plate*

In order to make comparison of photographs with non-reflecting and reflecting surface, the same laser beam was additionally diffracted from aluminium edge, and reflected from aluminium plate, photographs given in Fig. 6.

### 2.1 Economic analysis

Cost of drying for corn kernels were in United States (Michigan) at about 0.79 $/ton MC %, which amounts to 7.9 $/ton for the usual reduction from 24 % to 14 % MC from mean grain (kernels/seeds) moisture content at usual crop [PI]. Thus efficient reduction of moisture content from grain (kernels/ /seeds) at harvest time, which can be higher even higher than 24 % can yield further cost reduction. Expected moisture content decay is about 0.5 % /minute in driers when using 130 °C hot drying air.

## 3 RESULTS OF SPROUTING AND MYCOTIC POPULATION REMOVING PROCESS

Experiment consisted of two parts. The first part was laser beam treatment of grain for the purpose of measuring sprouting energy. This process is conducted in three steps: 1) seeds/kernels are wrapped in wet filter-paper and stored in controlled environment at temperature of 5 – 8 °C for 7 days; 2) seeds/kernels are then moved to environment at temperature of 20 °C for 4 days; 3) number of seeds that had sprouted are numbered and registered and this number is sprouting energy. This information can be expressed in percentage (%). Steps 2 and 3 can be repeated several times. Seeds/kernels for the first experiment were divided in two groups (A and B) with the same number of kernels and the same experiment was conducted in equal conditions. Intention was to repeat experiment and gain the same results for both experiments.

The second part of the experiment was detection of mycotic population (variety of fungi) before and after seeds have been exposed to laser beam.

In the first experiment artificially infected grains (seeds/kernels) were individually exposed to a 1 mW laser beam with 650 nm wavelength for 2–10 seconds. In the second experiment an array of 30 LED diodes, each with 650 nm wavelength and 5 mW power was used for irradiation of the seeds on the prototype conveyor belt, for different time duration. As shown in [4] and [5] a laser beam can remove excess moisture content and seed born fungi from grain.

Three cultivars of wheat seeds were used for the experiment and they are: »Super žitarka«, »Srpanjka« in the first and »Janica« in the second experiment.

### 3.1 Sprouting energy

Sprouting experiments were performed on all three cultivars of wheat seeds. Relative number of seeds that have ability to sprout is very important information for seeds that will be used in sowing. Sprouting is expressed as a ratio of number of sprouted kernels and total number of kernels in percentage (%) and must be higher than 85. Results are shown in table 1 and table 2.

Time exposures of »Srpanjka« are shorter because of smaller glade thickness.

Experiments conducted earlier determined that thicker glade seeds better scatters laser beam energy than thinner seeds.

Laser beam exposure time directly influence on sprouting – longer the time better sprouting. But the period of time that seeds are exposed to laser beam must not be too long (optimum is 3–10 seconds) because laser beam can damage embrio and kernel/seed can lose ability to sprout.

### 3.2 Mycotic population

The experiment was conducted in order to both determine which type of fungi can be removed by a laser beam and also to determine the removing efficiency. First group of artificially infected seeds were not treated with laser beam forming a control

Table 1 **Sprouting energy results for »Super žitarka« and »Srpanjka« cultivar of wheat seeds: divided in two groups, A and B; two weeks after treatment**

| Cultivar | Treatment | Energy | | Sprouting | |
|---|---|---|---|---|---|
| | | Group A | Group B | Group A | Group B |
| Super žitarka, highly infected | None | 28 | 25 | 56% | 54% |
| | Laser 2×5 seconds | 31 | 34 | 62% | 68% |
| | Laser 2×10 seconds | 42 | 38 | 84% | 76% |
| | Vitavax | 40 | 41 | 80% | 82% |
| Super žitarka, low infected | None | 45 | 44 | 92% | 90% |
| | Laser 2×5 seconds | 46 | 46 | 94% | 92% |
| | Laser 2×10 seconds | 45 | 45 | 90% | 90% |
| | Vitavax | 46 | 47 | 92% | 96% |
| Srpanjka, highly infected | None | 36 | 30 | 72% | 62% |
| | Laser 2×3 seconds | 40 | 33 | 82% | 66% |
| | Laser 2×6 seconds | 45 | 41 | 92% | 86% |
| | Vitavax | 42 | 45 | 84% | 90% |
| Srpanjka, low infected | None | 44 | 47 | 88% | 94% |
| | Laser 2×3 seconds | 49 | 45 | 98% | 92% |
| | Laser 2×6 seconds | 46 | 48 | 92% | 96% |
| | Vitavax | 48 | 47 | 96% | 94% |

Table 2 **Sprouting energy results for »Janica« divided in four groups one month after treatment**

| Cultivar | Treatment | Energy | | | | Sprouting |
|---|---|---|---|---|---|---|
| | | Group A | Group B | Group C | Group D | |
| Janica | None | 49 | 48 | 48 | 49 | 97% |
| | Laser 1 seconds | 48.5 | 48 | 49 | 49.5 | 97.5% |
| | Laser 2 seconds | 48.5 | 47.5 | 48.5 | 48.5 | 96.5% |
| | Laser 5 seconds | 47.5 | 48.5 | 48.5 | 46.5 | 95.5% |
| | Vitavax | 49 | 49 | 49 | 49 | 98% |

Table 3 **Types of fungi detected on »Janica« seeds one month after treatment**

| Cultivar | Treatment | Fungi | Level of infection (%) | Remark |
|---|---|---|---|---|
| Janica | None | Fusarium | 6.5 | |
| | | Helminthospor. | 0.5 | |
| | | Acremoniella | 2.0 | |
| | | Acremonium | 2.5 | |
| | | Alternaria | 29.5 | |
| | | Epicoccum | 1.0 | |
| | | Penicillium | 2.0 | |
| | | Phoma | 0.5 | |
| | Laser 1 second | Fusarium | 9.0 | Sprouts are greener than in control group |
| | | Helminthospor. | 1.0 | |
| | | Acremoniela | 0.5 | |
| | | Alternaria | 18.5 | |
| | | Chaetomiium | 0.5 | |
| | | Cladosporium | 0.5 | |
| | | Penicillium | 1.0 | |
| | | Trichoderma | 0.5 | |
| | Laser 2 seconds | Fusarium | 3.5 | Sprouts are greener than in control group |
| | | Helminthospor. | 0.5 | |
| | | Alternaria | 12.0 | |
| | | Cladosporium | 1.5 | |
| | | Penicillium | 1.0 | |
| | Laser 5 seconds | Fusarium | 2.0 | Sprouts are greener than in control group |
| | | Helminthospor. | 0.5 | |
| | | Alternaria | 12.5 | |
| | | Penicillium | 0.5 | |
| | Vitavax | Fusarium | 0.5 | Sprouts are very strong |
| | | Penicillium | 0.5 | |

Table 4 **Types of fungi detected on »Super žitarka« and »Srpanjka« seeds two weeks after treatment**

| Cultivar | Level of infection | Treatment | Fungi | Level of infection (%) |
|---|---|---|---|---|
| Super žitarka | Highly infected | None | Fusarium | 30 |
| | | | Penicillium | 34 |
| | | | Alternaria | 1 |
| | | Laser 2×5 seconds | Fusarium | 25 |
| | | | Alternaria | 1 |
| | | Laser 2×10 seconds | Fusarium | 16 |
| | | | Penicillium | 1 |
| | | | Alternaria | 1 |
| | | Vitavax | Fusarium | 9 |
| | Low infected | None | Fusarium | 4 |
| | | Laser 2×5 seconds | Fusarium | 5 |
| | | Laser 2×10 seconds | Fusarium | 7 |
| | | Vitavax | – | 0 |
| Srpanjka | Highly infected | None | Fusarium | 23 |
| | | Laser 2×3 seconds | Fusarium | 24 |
| | | Laser 2×6 seconds | Fusarium | 3 |
| | | | Alternaria | 3 |
| | | Vitavax | Fusarium | 9 |
| | Low infected | None | Fusarium | 3 |
| | | | Penicillium | 1 |
| | | | Alternaria | 1 |
| | | Laser 2×3 seconds | Fusarium | 3 |
| | | | Alternaria | 1 |
| | | Laser 2×6 seconds | Fusarium | 2 |
| | | Vitavax | – | 0 |

group. Seeds from the other groups were exposed to laser beam energy in a specified time frame or were exposed to chemical substrate – fungicide. Chemical substrate used in the experiment was Vitavax – seed treatment fungicide consisting of two components, liquid and powder. Kernels are sprinkled with liquid component in the first stage of the process and then second component (powder) is applied. The detected fungi on seed surface are shown in Table 3 and Table 4. The time period between laser stimulation of seed and their sprouting and fungi test was one month for »Janica« and two weeks for »Super žitarka« and »Srpanjka« cultivar.

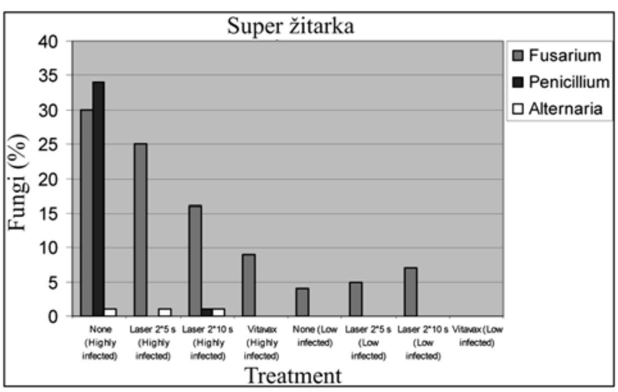



*Fig. 7 Mycotic population on artificially infected »Super žitarka« wheat seeds*

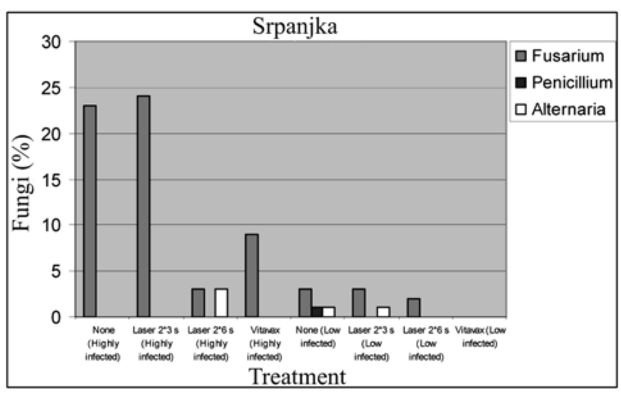



*Fig. 8 Mycotic population on artificially infected »Srpanjka« wheat seeds*

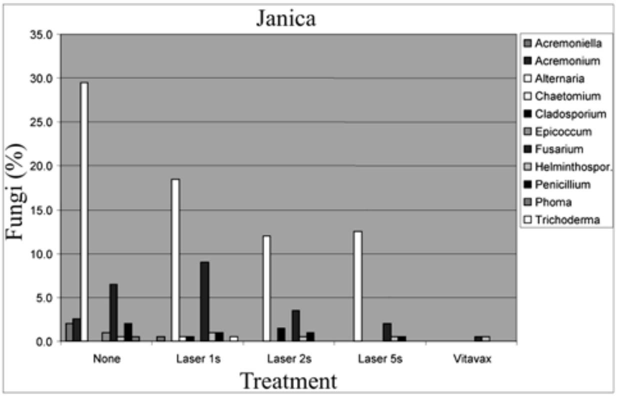



*Fig. 9 Mycotic population on artificially infected »Janica« wheat seeds*

Level of infection in table 3 represents the ratio of the number of kernels infected with any type of fungi regardless of treatment and the total number of grains.

Results form Table 3 and Table 4 are presented on cultivars of seeds.

## 4 A PROTOTYPE OF AN AUTOMATED DEVICE FOR LASER TREATMENT OF SEEDS

A model of production line was constructed and tested in this experiment as shown in Fig.10. Device consists of PCBs (Printed Circuit Board), conveyer belt with driver electromotor, and grain container.

Printed circuit board consists of an squared array ($80 \times 80$ mm) of 5 mW low power laser diodes distributed on a PCB in such a way that every grain passing under PCB on conveyer belt is exposed at least to one laser beam. Conveyor belt speed can be regulated by a driver electromotor. Seeds can be exposed to a laser beam with different time duration depending on the conveyer belt speed. By controlling time duration of seed exposure, absorbed energy of seeds can be controlled as well. Different energy exposures of the seeds resulted in different energy absorbed by the seeds both for chemically treated and untreated seeds. The observed effects will be discussed later in the paper.

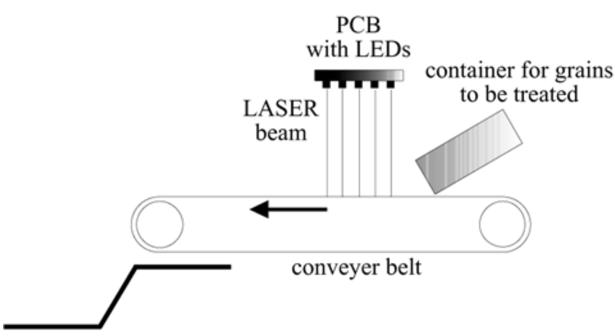



*Fig. 10 Prototype schematics*

### 4.1 Possible applications

Device for laser treatment of seeds could be mounted on seeder units, combine harvesters or conveyors, and new designs of proposed equipment will include it. Figures 11a and 11b show mounting laser diodes to transparent conduit through which kernels/seeds are directed.

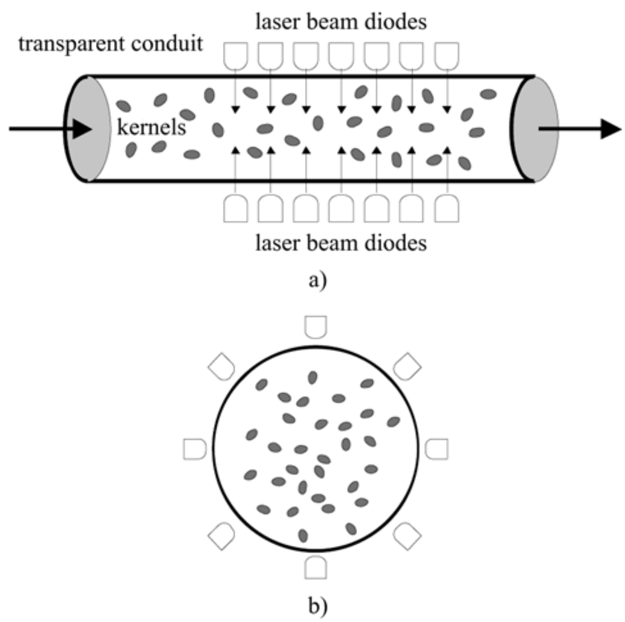



*Fig. 11 Laser diodes mounting around transparent hose; a) body plan; b) cross section*

Large numbers of mounted laser diodes around transparent hose ensure that every kernel/seed is exposed to laser beam. Proposed model can perform both functions – excess moisture removing and mycotic population removing.

## 5 SIMILARITY ANALYSIS

Integrating artificial intelligence (AI) methods into natural decision support systems (NDCS) provides users with more accurate and reliable NDCS. Case-based reasoning (CBR) can be a good technique in making estimations in uncertain state situations [3]. CBR is based on the comparison of the most similar cases or experiences among those stored in the case base. If there are only analogies stored then the only way of using these analogies is to adapt the most similar one. Thus the key element in obtaining a reliable state classification is the similarity measure.

Two cases x and y are related with the similarity measure if the respective attribute differences can be normalized within the interval [0, 1] by means of the relation

$$\mathrm{SIM}\ (x,\ y) = 1 - \mathrm{DISS}\ (x,\ y) \qquad (1)$$

where each respective attribute in x has a corresponding analog atribute in y. Dealing with pure quantitative data similarity measures such as Minkowski's metric, weighted or unweighted measures, heterogenous measures or L'Eixample measure have been applied to databases with various number and type of characteristics [7].

The main dissadvantage of these measures is, beside their accuracy spread out, foundation on estimated probabilities and correlation. Principally quantitative correlations are performed on the assumption of data set linearity which is an essential mistake. Our aproach to similarity analysis is based on qualitative data transposition to ordinaliry numbers and on qualitative data correlation which is in principle nonlinear data comparison method. The dissimilarity is expressed in qualitative transpozed data as

$$\mathrm{DISS}\ (xr,\ yr) = \frac{6\sum \Delta^2}{n\left(n^2 - 1\right)} \qquad (2)$$

where $\Sigma\Delta^2$ represents the sum of squared rank differences on correspondent $n$ variable measurement instances. Similarity measures of energy for data A and B on Table 1 for two sorts of grain are calculated according to (1) and (2) are, are presented in Table 5.

Table 5 **Qualitative similarity measures for energy for data from Table 1**

| | Super žitarka A | Srpanjka A | |
|---|---|---|---|
| Super žitarka B | 0.964 | 0.905 | |
| Srpanjka B | 0.760 | 0.654 | 0.821 |
| | 0.952 | | |

## 6 DISCUSSION

Every chemical substrate that can harm any living being is harmful to humans too. Laser treatment can minimize usage of chemicals in seeds preprocessing thus lowering influence on chemical pollution of soil where seeds are to be seated. It can be mentioned that laser beam treatment is an environmentally safe process.

As shown in Table 1 and Table 2 sprouting efficiency of grains exposed to laser beam and chemically treated seeds/kernels differs slightly, i.e. 1–3 percent. This result can open discussion on environmentally safe grain treatment rather than chemical treatment. One can also observe that laser beam can completely remove some types of fungi and significantly reduce remaining types of seeds fungi, as shown in Tables 1, 2, 3, and 4, and in Figures 7, 8 and 9. This is important because some types of fungi have toxic effect on humans and also fungi fed seeds starch, thus reducing their nutritive value for embrio. More resistant fungi are not completely removed from seeds/kernels, like Fusarium and Helminthosporum, but most of fungi are completely removed or reduced to acceptable number.

Further experiments will determine the best time interval for seed's exposure to laser beam.

Also, further experiments and research will be based on energy emissions both from non treated seeds/kernels (by means of laser beam exposure) and laser beam treated seeds/kernels. Laser diode energy should be kept effective in stimulating embrio and removing fungi rather than increasing seed's temperature. For this experiment a thermovision camera is planned to be used. Further experiments will be conducted with pulse mode diodes rather than continuous to determine which type of diodes is more effective for grain processing. Emission spectrum from seeds/kernels will be also observed for both laser treated seeds/kernels and spontaneous from non treated seeds/kernels.

Main issue in agriculture is environmental impact [2]. Low power laser treatment of seeds/kernels shown in the paper is environmentally safe.

Results presented in [4] and [5] and in this paper show that laser beam treatment applied to seeds//kernels can significantly reduce number of fungi and increase the number of sprouted grains. This is important because any type of chemicals used to remove fungi from seeds are harmful for fungi but also for human. Laser beam treated seeds/kernels show high percentage in sprouting and greener sprouts than untreated seeds/kernels, one feature that needs to be investigated further. Laser beam treatment has more than one positive effect on seeds/kernels: the fungi removing effect and seeds//kernels embrio stimulation.

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**Istraživanje automatske obrade sjemena laserskom zrakom male snage.** Rad opisuje dva skupa uzastopno izvedenih pokusa obrade kukuruznih i pšeničnih zrna laserom male snage. Prvi je pokus proveden korištenjem laserske zrake za odvođenje površinske vlage kukuruznih zrna. Drugi je pokus proveden za određivanje utjecaja laserske zrake male snage na mikotičku populaciju zrna pšenice. Da bi se odredilo ispravno doziranje, zrna su bila umjetno zaražena različitim plijesnima poput Peniciliuma, Fusariuma, Alternariom i sl. i to u dva stupnja zaraze (veliki i mali stupanj). Pokus je planiran usporedno s kemijskim tretmanom zrna, kako bi se utvrdio usporedni učinak laserske obrade zrna na klijavost, koja se definira kao postotak proklijalih zrna nakon specifičnog vremena inkubacije, te na preživljavanje plijesni, izraženo kao razina zaraženosti. Pokusni sustav s tračnim konvejerom izrađen je za izlaganje zrna laserskoj zraci u potonjem skupu pokusa. Laserska je obrada bila do neke mjere učinkovita u povećanju klijavosti i smanjenju preživljavanja plijesni, iako u ovim prethodnim pokusima ne tako učinkovita kao obrada zrna fungicidima. Ovaj rad predlaže izradu automatskog uređaja za lasersku obradu kao okolišno sigurnije inačice kemijskom postupku pri različitim kultivarima sjemena.

**Ključne riječi**: otklanjanje suvišne vlage, kukuruzna i pšenična zrna, umjetno zaraženo pšenično zrno, obrada laserskom zrakom, predobrada zrna, procesna automatika, okolišno siguran proces

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