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Comparison of Fiber Reinforced Polymer (FRP) Composite Blade with Steel Blade Performance Used in Chisel Plow

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Abstract

All over the world, farmers choose different implements for tillage, which depend on crop type, soil type, the amount of plant residue from the previous crop, etc. Tillage implement selection is also affected by the availability of implements, power consumption, labor costs, and fund. In this research, the draft force, soil disturbance area, soil cone index, and fuel consumption were considered. The effects of rake angle, forward speed, and soil moisture content on the above-mentioned parameters were investigated. In this research, a comparison between the performance of a Fiber Reinforced Polymer (FRP) composite blade and a conventional steel blade was carried out. Tests were based on the split-split plot in a completely randomized design. The factors of soil moisture content, rake angle, and forward speed were included in three levels. Three levels for the soil moisture content (9.3, 13, 16.7 %), rake angle (20°, 30°, 40°), and forward speed (3, 5, 7 km.h⁻¹), were considered. The FRP composite blade (on average in the desired range for variables) has reduced the draft force, fuel consumption, and soil cone index, 14.97%, 16.63%, and 35.08%, respectively, than the steel blade. Also, the soil disturbance area created by the FRP composite blade was 4.93% higher than the steel blade. Based on the results of this study, it is clear that the FRP composite blade has better performance rather than the conventional steel blade for the aforementioned test variables. The FRP composite is inexpensive than the steel, this leads to remarkable save money in the production of the FRP composite blade used in the chisel and combined tillage tools that is economical for the farmer and manufacturer.

Keywords: Forward speed, FRP composite blade, Rake angle, Soil moisture content, Steel blade

Introduction

Tillage operation is the most important step in the production of crops and provision of agricultural land that consumes a great amount of power and energy. In the past decades, several tillage tools have been designed to achieve the main purpose of the tillage operation. Although a farmer is free to choose any of the tools, he always attempts to recognize their consumption energy and choose them according to the cultivation conditions (Godwin, 2007). The amount of energy used in tillage is very high compared to the other agricultural operations. Therefore, saving a small portion of consumption energy in agricultural operations will reduce the costs (Sanchez-Giron et al., 2005). Due to the problems of conventional tillage, the conservation tillage in the form of minimum and no-tillage was introduced gradually. For this purpose, implements such as chisel and combined tillage tools were developed. The most important part of these tillage tools is their blade, which is typically made from steel. Adjustment of the blade is effective on draft, fuel consumption, and plowing quality. However other factors such as soil moisture content, forward speed, depth of tillage, and blade angles also have significant effects on...
the plowing quality (Liu and Kushwaha, 2006).

Some researchers investigated the effects of forward speed, rake angle, and soil moisture content on several factors such as draft force (Akbarinia et al., 2014; Ibrahmi et al., 2015), soil disturbance area (Manuwa, 2009; Jafari et al., 2011), fuel consumption (Ranjbarian et al., 2017), and cone index (Kumar et al., 2012). Khalilian et al. (1998) compared the required draft force of the tillage tools including subsoiler, the Para plow, and chisel plow at different tillage depths. They estimated the amount of draft force for the chisel, subsoiler, and Para plows as 2.88, 4.45, and 5 kN, respectively. Rahman and Chen (2001) compared two types of disk tillage tools and sweep plows in terms of soil disturbance area. They considered the applied treatments as the depth of tillage and forward speed and reported that with increasing the tillage depth and forward speed, the amount of soil disturbance area increased in both tillage tools, and the sweep blades showed better performance rather than the disk in soil disturbance area. Chaplain et al. (2011) showed that the continuity in the no-tillage causes to increase in the bulk density, mechanical strength of the soil, and the soil cone index, which results in reducing water infiltrations and also root reduction in the soil, and increasing soil erosion. The results of some researches on the fuel consumption of the tractor showed that increasing the forward speed and depth of tillage increased the fuel consumption (Al-Jasim, 1993; Ranjbarian et al., 2017).

Some other researchers, using other materials in the form of the cover or employing the main materials for making the blade, tried to improve draft force, fuel consumption, etc. (Soni et al., 2007; Barzegar-Tabrizi et al., 2017). Chen et al. (1990) used Teflon as a coating on the surface of a moldboard plow to reduce soil-tool friction and they reported that Teflon coating causes draft force decreases. Salokhe et al. (1990) reported that the enamel-coated plows reduced draft force by up to 14% and 16% at 3.6 and 4 km.h\(^{-1}\), respectively. Soni et al. (2007) constructed the moldboard plow which was covered with rows of ultra-high molecular weight polyethylene (UHMW-PE), as the material with low viscosity and friction, and its draft force was compared with steel moldboard plow in the adhesive soil. The results indicated that the draft force of the moldboard plow with a UHMWPE coating was 36% less than that of the moldboard plow. Barzegar et al. (2016) covered a furrower with ultra-high molecular weight polyethylene (UHMW-PE) and examined on the blade the draft force and adhesion. Their results showed that the UHMW-PE coating reduced the draft force and adhesion.

Recent studies on comparing plow types, changing the blade's material, and finding the best performance in the tillage operations indicated that the researchers are seeking the best performance with the lowest cost and power consumption in the tillage operation. The purpose of this research was to evaluate the performance of the Fiber Reinforced Polymer (FRP) composite blade compared to conventional steel ones. The factors of this research were including draft force, fuel consumption, soil disturbance area, and cone index. Performance comparison such as draft force, soil disturbance area, etc. of the FRP composite blade and conventional steel one (considering the effect of the blade properties, such as weight, adhesion, etc., but without considering the abrasive wear blade) was carried out in the field. The purpose of this research is to present the FRP composite blade and compare it to the steel blade in terms of impact on the mentioned factors.

**Materials and Methods**

**Tillage site**
Field experiments were conducted in farm No. 10 of Agriculture school (29°43'41"N 52°34'51"E) of Shiraz University, located in Bajgah zone of Fars province, Iran. The soil texture at the experimental site was clay loam with 38% clay, 30% sand, and 32% silt. To do experiments, a total of 27 plots were selected at a predetermined size (30 × 15 m) in the field. Soil moisture content was measured at 10 random locations of each plot prior to the tests. Initial soil moisture content was 7.2 ± 1.3 (d.b %). Also, to measure the soil bulk density, a standard cylinder with a diameter of 5 cm and a height of 10 cm was used, and the bulk density of 1.8 ± 0.4 (g.cm⁻³) was obtained.

**Tractor and tillage implement specifications**

In this research, a 4WD tractor (model: ITM-399) was used that produced in the Iran Tractor Manufacturing Company. The plow used in this research was the mounted type chisel plow, constructed by Oztoprac Company in Turkey. The plow had a shank and two gauge wheels on both sides. Also, a mechanism was installed on it for adjusting the rake angle (Fig.1).

![Fig.1. Mechanism for adjusting the rake angle](image)

**Blades**

In this research, two chisel blades made of steel (controlling factor) (Fig.2C) and FRP composite (Fig.2B) were compared. The reason to use the FRP composite instead of steel in the chisel blades is due to its similarity or superiority at some mechanical factors over steel (Zhou et al., 2019). FRP materials are more resistant than steel in terms of the tensile strength (Jauharia et al., 2016). Also, the specific weight of the FRP composite is less than that of the steel (Biscaia and Chastre, 2018), such as the specific weight of FRP composites is one-third that of steel. The ultimate tensile strength for steel and FRP composite is 390 and 1200 MPa, respectively. Also, the young’s modulus of the steel and FRP composite is 200 and 55 GPa, respectively (Mazaheri et al., 2015). In FRP materials, the volume fraction, size, and cross-sectional area of the FRP fibers used essentially affect their resistivity (Biscaia and Chastre, 2018). FRP composite blade used in this study, was prepared from FRP composite pipes manufactured by Farassan Company (Fars province, Iran). The FRP composite blade was cut off by using a laser cutting technique, according to steel blade pattern, with the same curvature and width (5 cm) (Figures 2B and 2C). The FRP composite toughness is less than steel (Mazaheri et al., 2015), therefore, to strengthen the composite blade against impact and better soil cutting, a steel plate (thickness of 8 mm and length of 250 mm) was installed as a base under the FRP composite blade (Fig.2A). For comparison of two blades with the same conditions, the surface area of the FRP composite blade with its support was the same as the surface area of the steel blade.
To measure the friction between blades and soil, the adhesion index and external friction angle were used. For this purpose, in this study, a device similar to the devices of Gill and Van Den Berg (1968) and Kepner et al. (1972) was used to measure the adhesion and angle of external friction. To measure cohesion, the shear and vertical stresses of the soil at the desired moisture contents were measured by using a direct shear test machine manufactured by the Azmoon Company, Iran. Then, by using the Mohr-Coulomb theory, the cohesion, adhesion, and external friction angle for FRP composite and steel blades were obtained (Table 1). The blades' weight, shank weight, and total weight of the plow were affected the draft force and fuel consumption of the tractor (Karpavarfard and Rahmanian-Koushkaki, 2015). Therefore, the weight of the blades in this research was measured. For this purpose, weights were obtained by using a digital scale (model: MDS15000AP) with the accuracy of ±2g, manufactured by Mahak Company, Iran. Net weight of the steel and the FRP composite blades, net weight of the support, total weight of the FRP composite blade, and its support were obtained 1.355, 0.230, 0.830 and 1.065 kg, respectively.

Table 1- Mechanical and physical properties of farm soil

<table>
<thead>
<tr>
<th>Moisture content (%)</th>
<th>Soil cohesion (kPa)</th>
<th>Steel chisel blade</th>
<th>FRP composite chisel blade</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Soil adhesion (kPa)</td>
<td>Angle of external friction (°)</td>
<td>Soil adhesion (kPa)</td>
</tr>
<tr>
<td>9.3</td>
<td>2.23</td>
<td>1.01</td>
<td>24.20</td>
</tr>
<tr>
<td>13</td>
<td>3.26</td>
<td>1.40</td>
<td>22.90</td>
</tr>
<tr>
<td>16.7</td>
<td>4.37</td>
<td>2.14</td>
<td>20.40</td>
</tr>
</tbody>
</table>

Field tests

The experimental variables in this research were forward speed (3, 5, and 7 km.h⁻¹), rake angle (20°, 30°, and 40°), and soil moisture content (9.3, 13, and 16.7%). The depth of tillage in all experiments was 25 cm. Tests were based on the split-split plot in a completely randomized design. To obtain the tillage depth of 25 cm, several trials were performed by using the desired plow. Several times, for measure tillage depth by using a laser ruler, from the plowed furrow floor to the surface soil was measured. This work was done to fine-tune the tillage depth of the plow in the tillage operation. After reaching a tillage depth of 25 cm, the depth of tillage was fixed using gauge wheels on both sides of the chisel plow.

To obtain the desired moisture content in the field, the whole farm was irrigated using a flooding irrigation system. Then, on a daily basis, soil moisture was measured, and by observing the desired moisture content (from the highest moisture to the lowest moisture),
experiments related to those desired moisture content were performed.

**Draft force and fuel consumption**

A digital system was employed to measure the draft force and the fuel consumption of the tractor (Rahmanian-Koushkaki *et al.*, 2015). This digital system had 11 ports. Two encoder shafts, two fuel transducers, and one load cell were used and connected to it to measure the draft force and fuel consumption (Fig.3). By using the RS232 cable the data was transformed to a Laptop and displayed and saved (Fig.3).

Draft force is the force applied from the soil on the blade and shank of the plow. The RNAM test code was used to measure the reaction force from soil to blade (RNAM Standard, 1995). For this purpose, a traction dynamometer (S type) was used (Table 2). Actual forward speed was measured using two shaft encoders (Fig.3). They were mounted on the center of the fifth wheel and right rear wheel of the tractor for measuring the actual and theoretical forward speed, respectively (Karparvarfard and Rahmanian-Koushkaki, 2015).

Two turbine flow transducers were also used to measure fuel consumption (Table 2). One of them was installed between fuel filters and injector pump of the tractor and the other between the injectors and the fuel tank were placed (Fig.3) (Shafaei *et al.*, 2018). The difference between values measured by two turbine flow transducers indicates the actual fuel consumption.

**Fig.3.** (A) Package of the laptop and data acquisition; (B) Load cell; (C) Turbine flow transducer; (D) Rotary shaft encoder. (Dark blue line is the connection wire).

**Table 2** - Specification of equipment used

<table>
<thead>
<tr>
<th>T. No.</th>
<th>Name of the transducer</th>
<th>Specification</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Vision-1000, Turbine flow transducer (2 Nos.)</td>
<td>0.1-2.5 l.min⁻¹ (22,000 pulse.l⁻¹), ±3%</td>
<td>Remag, Switzerland</td>
</tr>
<tr>
<td>2</td>
<td>ES05B-500-3-N-24, Shaft encoder (2 Nos.)</td>
<td>500 pulse.revolution⁻¹, ±5%</td>
<td>Autonics, South Korea</td>
</tr>
<tr>
<td>3</td>
<td>DEE-5t, Traction dynamometer</td>
<td>S type, range 0-50 kN, precision grade: C₃</td>
<td>Keli, China</td>
</tr>
</tbody>
</table>

Soil disturbance area and cone index
For measuring the soil disturbance area in each plot, a transverse cut equal to the size of the soil disturbance, was created in the soil. After drawing out the soil, the profilometer was placed on the soil surface. The distance between the profilometer rods was 2 cm. Thus, several points of soil disturbance area were obtained by profilometer (Conte et al., 2011; Hang et al., 2017). Then, by using these points and Simpson's rule (Eq. 1), the soil disturbance area in each plot was computed.

\[
\int_a^b f(x)dx = \frac{h}{3} \left[ f(x_0) + 2 \sum_{j=1}^{N/2-1} f(x_{2j}) + 4 \sum_{j=1}^{N/2} f(x_{2j-1}) + f(x_N) \right]
\]

Where \(a\) and \(b\) are the minimum and maximum values among the points obtained by the profilometer, respectively. \(N\) is the number of used data points and \(h\) is \((b-a)/2N\).

Cone index was used to measure the amount of soil softness. The soil cone index was measured according to the ASABE standard (ASABE, 2006a) and by using the penetrometer (SP-1000) manufactured by Findly Irvine, Scotland. For this purpose, the cone index was randomly measured at several points in the field before doing the experiments. Also, after each experiment, the cone index was measured with 5 replications in each plot.

**Results and Discussions**

**Draft force and fuel consumption**

The draft force value for the steel and FRP composite blades at different levels of soil moisture content, rake angle, and forward speed are shown in Figures 4, 5, and 6. Based on these results, the amount of draft force of the FRP composite blade is less than that of the steel one at different levels of soil moisture content, rake angle, and forward speed. The reduction of the draft force of the FRP composite blade compared to the steel blade in the moisture content of 9.3, 13, and 16.7% were obtained at 11.94% (0.56 kN), 23.40% (1.43 kN), and 11.67% (0.77 kN), respectively (Fig.4). This reduction was also reported at the rake angle of 20°, 30°, and 40° as 10.67% (0.57 kN), 18.50% (1.11 kN), and 14.00% (0.87 kN), respectively (Fig.5), and the reduction of the draft force at the forward speed of 3, 5 and 7 km.h\(^{-1}\) were 16.64% (0.91 kN), 10.70% (0.59 kN) and 17.24% (1.16 kN), respectively (Fig.6). According to Table 1, the adhesion value of the FRP composite blade is lower than the adhesion of the steel blade. Therefore, the soil movement on the FRP composite blade is decreased according to the ASABE standard (ASABE, 2006a) and by using the penetrometer (SP-1000) manufactured by Findly Irvine, Scotland. For this purpose, the cone index was randomly measured at several points in the field before doing the experiments. Also, after each experiment, the cone index was measured with 5 replications in each plot.

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Fig. 4. Comparison between the draft force of steel blade and FRP composite blade at different moisture content levels (blue rectangle: steel blade; orange rectangle: FRP composite blade; green rectangle: difference between steel blade and FRP composite blade)

In Fig. 5, by increasing the rake angle, the draft force of two FRP composite and steel blades was increased. By increasing the rake angle, the projected area of the blade increases for contact with intact soil (Aluko and Seig, 2000). Therefore, by increasing the blade contact surface at the initial impact to the intact soil, more force is applied to the blade from the soil, and draft force increases. Thus, with increasing rake angle, the draft force increases (Aluko and Seig, 2000; Godwin, 2007).

Fig. 5. Comparison between the draft force of steel blade and FRP composite blade at different rake angles (blue rectangle: steel blade; orange rectangle: FRP composite blade; green rectangle: difference between steel blade and FRP composite blade)
In Fig. 6, it is revealed that with increasing the forward speed, the draft force of the FRP composite and steel blades increased. As the forward speed increases, the blade movement acceleration increases in the soil. According to Newton's second law, with increasing the acceleration of the blade movement in the soil, the force applied to the soil particles increases, and consequently, the soil particles applied more reaction force to the blade, and the draft force increases. Therefore, with increasing forward speed, the draft force increases (Akbarnia et al., 2014; Ibrahimi et al., 2015).

Fig. 6. Comparison between the draft force of steel blade and FRP composite blade at different forward speeds (blue rectangle: steel blade; orange rectangle: FRP composite blade; green rectangle: difference between steel blade and FRP composite blade)

Figures 7, 8, and 9, show fuel consumption values of FRP composite and steel blades at different levels of moisture content, rake angle, and forward speed. These figures indicated that the fuel consumption of the FRP composite blade is reduced than the steel blade. Since the fuel consumption is directly related to draft force (Shafaei et al., 2017; Shafaei et al., 2018), with increasing draft force, the fuel consumption increases. Due to the less draft force of the FRP composite blade than the steel blade at different levels of moisture content, rake angle, and forward speed (Figures 4, 5, and 6), the fuel consumption of the FRP composite blade was lower than that of the steel blade.

The reduction of the fuel consumption related to the FRP composite blade compared to the steel blade in the moisture content of 9.3, 13, and 16.7% were obtained as 11.36% (0.05 l.min\(^{-1}\)), 12.77% (0.06 l.min\(^{-1}\)), and 17.65% (0.09 l.min\(^{-1}\)), respectively (Fig. 7). This reduction was also reported at the rake angles of 20°, 30°, and 40° were obtained as 23.08% (0.12 l.min\(^{-1}\)), 20.75% (0.11 l.min\(^{-1}\)), and 21.82% (0.12 l.min\(^{-1}\)), respectively (Fig. 8) and the reduction of the fuel consumption at the forward speed of 3, 5, and 7 km.h\(^{-1}\) were obtained as 16.67% (0.07 l.min\(^{-1}\)), 16.00% (0.08 l.min\(^{-1}\)), and 9.62% (0.05 l.min\(^{-1}\)), respectively (Fig. 9).

Figures 7, 8, and 9 show that fuel consumption is increased with increasing the moisture content, rake angle, and forward speed. With increasing draft force at different levels of moisture content, rake angle, and forward speed (Figures 4, 5, and 6), the tractor should consume more power to move the
blade in the soil and overcome the draft force. Increasing the power consumption by the tractor leads to an increase the fuel consumption. As a result, with increasing moisture content, rake angle, and forward speed, the fuel consumption also increases (Zhang et al., 2016; Shafaei et al., 2018).

Fig. 7. Comparison between the fuel consumption of steel blade and FRP composite blade at different moisture content levels (blue rectangle: steel blade; orange rectangle: FRP composite blade; green rectangle: difference between steel blade and FRP composite blade)

Fig. 8. Comparison between the fuel consumption of steel blade and FRP composite blade at different rake angles (blue rectangle: steel blade; orange rectangle: FRP composite blade; green rectangle: difference between steel blade and FRP composite blade)
Soil disturbance area and cone index

The soil disturbance area shows the soil failure area (Solhjou et al., 2014; Hang et al., 2017). Due to the less adhesion of the FRP composite blade than the steel blade (Table 1), the soil particles can move easily on the blade and leads to more displacement of soil particles. With these explanations and according to figures 10, 12, and 13, it can be concluded that the soil disturbance area created by the FRP composite blade is more than the steel blade.

The soil disturbance area of the FRP composite blade than the steel blade in the moisture content of 9.3, 13, and 16.7% were increased which obtained as 4.52% (23.17 cm²), 5.16% (25.93 cm²), and 5.08% (24.74 cm²), respectively (Fig.10). Also, this increase was reported at the rake angle of 20°, 30°, and 40° as 4.39% (21.67 cm²), 5.96% (30.37 cm²), and 6.22% (32.24 cm²), respectively (Fig.12).

The increase of soil disturbance area of the FRP composite rather than steel blade at the forward speed of 3, 5, and 7 km.h⁻¹ were obtained as 3.68% (18.05 cm²), 3.66% (18.19 cm²), and 5.71% (28.99 cm²), respectively (Fig.13). According to Table 1, with increasing the soil moisture content, cohesion value increases. The high value of soil cohesion leads to the formation of a strong bond among soil particles. Also, by increasing soil moisture content, the soil adhesion was increased (Table 1), which caused slower movement of the soil on the blade. With these explanations, it can be concluded that with increasing the soil moisture content, soil particles movement has been decreased and the soil disturbance area also decreased (Fig.10) (Rahmatian et al., 2018).

Fig.9. Comparison between the fuel consumption of steel blade and FRP composite blade at different forward speeds (blue rectangle: steel blade; orange rectangle: FRP composite blade; green rectangle: difference between steel blade and FRP composite blade)
Fig. 10. Comparison between the soil disturbance area of steel blade and FRP composite blade at different moisture content levels (blue rectangle: steel blade; orange rectangle: FRP composite blade; green rectangle: difference between steel blade and FRP composite blade)

Fig. 2, shows that the soil disturbance area increased by increasing the rake angle. By increasing the rake angle blade, the projected area of the blade on the intact soil has been increased and at one time, the more surface of the blade hits with the soil and leads to displacement of more soil particles in the soil (Fig. 11). For this reason, with increasing the rake angle blade, the soil disturbance area increases (Jafari et al., 2011).

Fig. 11. Schematic project blade on the soil: (A) soil, (B) tillage tool, (C) project blade on the soil, and (a) rake angle
Fig. 12. Comparison between the soil disturbance area of steel blade and FRP composite blade at different rake angles (blue rectangle: steel blade; orange rectangle: FRP composite blade; green rectangle: difference between steel blade and FRP composite blade).

Fig. 13. Comparison between the soil disturbance area of steel blade and FRP composite blade at different forward speeds (blue rectangle: steel blade; orange rectangle: FRP composite blade; green rectangle: difference between steel blade and FRP composite blade).

Fig. 12 shows the effect of the forward speed on the soil disturbance area. According to Fig. 13, with increasing the forward speed, the soil disturbance area has been increased (Manuwa, 2009; Jafari et al., 2011). With increasing forward speed, the displacement of soil particles increases, and consequently, the soil disturbance area increases.
The cone index of the soil is an indicator for measurement soil softening for water and root penetration in soil (Goodin and Priddy, 2016; Pillinger et al., 2018). By increasing the soil disturbance area, the soil is softened and the penetration becomes easier. For this reason, the soil cone index decreased (Figures 14, 15, and 16) with increasing soil disturbance area at different levels of moisture content, rake angle and forward speed in this study (Figures 10, 12, and 13) (Tagar et al., 2014; Goodin and Priddy, 2016). The reduction amount of soil cone index of the FRP composite blade than the steel blade in the moisture content of 9.3, 13, and 16.7% were obtained 37.12% (1.21 MPa), 34.29% (1.20 MPa), and 30.23% (1.20 MPa), respectively (Fig.14). This reduction was also found at the rake angle of 20°, 30°, and 40° as 31.58% (1.26 MPa), 33.51% (1.24 MPa), and 38.94% (1.18 MPa), respectively (Fig.15) and at the forward speed of 3, 5, and 7 km.h⁻¹ were obtained 26.55% (1.24 MPa), 41.46% (1.31 MPa), and 42.07% (1.22 MPa), respectively (Fig.16).

In Fig.14, it has been shown that with increasing soil moisture content, the value of the cone index increases (Patel et al., 2013; Lin et al., 2014). Due to the increase of moisture content, the cohesion between soil particles is increased (Table 1). Therefore, the soil disturbance area has been decreased (Fig.10), which causes less soil softening, and the soil cone index increases. In figures 13 and 14, with the increase of the rake angle and forward speed, the soil cone index decreased (Tagar et al., 2014) that this reason is due to the reduction of soil disturbance area when increasing the rake angle and the forward speed (Figures 12 and 13).

Fig.14. Comparison between the cone index of steel blade and FRP composite blade at different moisture content levels (blue rectangle: steel blade; orange rectangle: FRP composite blade; green rectangle: difference between steel blade and FRP composite blade)
Fig. 15. Comparison between the cone index of steel blade and FRP composite blade at different rake angles (blue rectangle: steel blade; orange rectangle: FRP composite blade; green rectangle: difference between steel blade and FRP composite blade)

Fig. 16. Comparison between the cone index of steel blade and FRP composite blade at different forward speeds (blue rectangle: steel blade; orange rectangle: FRP composite blade; green rectangle: difference between steel blade and FRP composite blade)
Economic comparison
Economic issues, one of the important stages in the engineering design that must be considered (Stanic et al., 2016). According to the prices presented by the New York Stock Exchange (NYSE) for steel and FRP composites in 2018 and 2019, it is observed that FRP composites have lower prices on the world market than steel (Fig.17). Also, according to section blades, the FRP composite specific weight is less than that of the steel. Therefore, more blades can be produced with larger volumes of FRP composites per kilogram than steel. According to this information, the use of FRP composite instead of steel for making the chisel blade in terms of economical is affordable. The high production of FRP composite blades with lower cost than steel blades leading to reduce the cost of blade manufacturers and also increases profitability. Of course, due to fluctuations in the world market for gold and oil had a great impact on the price of steel and FRP composite, which in 2018 and 2019 cause to rise or fall in the price of steel and FRP composites in dollar terms (Fig.17), but the price of FRP composite is still lower than steel prices.

Fig.17. Price comparison in dollar terms between steel and FRP composite in 2018 and 2019 retrieved from New York Stock Exchange (NYSE) site (blue line: steel price; orange line: FRP composite price)

Conclusion
The obtained results from field tests showed that the FRP composite blade (on average in the desired range for variables) has reduced the draft force, fuel consumption, and soil cone index, 14.97%, 16.63%, and 35.08%, respectively, than the steel blade. The soil disturbance area created by the FRP composite blade was 4.93% higher than the steel blade. According to the comparison of FRP composite blade and steel blade in terms of draft force, fuel consumption, soil disturbance area, and cone index in the experimental field, and economic comparison between these two blades, FRP composite blade operation was better and more suitable. According to the results of this research in terms of tillage and economic, the use of the FRP composite blade is recommended to farmers and blade manufacturing. It is suggested that the FRP composite blade checking at different tillage depths and in the subject of abrasive wear, so that information on the characteristics of the FRP composite blade in the tillage operation to be complete.
References


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مقایسه عملکرد تیغه کامپوزیت پلیمر تقویت شده با الیاف (FRP) با تیغه فولادی مورد استفاده در گاوآهن قلمی

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چکیده

در سراسر دنیا، کشاورزان از ابزارهای مختلفی برای خاک وری انتخاب می‌کنند که این به نوع محصول، نوع خاک، باقیمانده گیاه از محصول قبلی و غیره بستگی دارد. انتخاب ابزار کشاورزی نیز تحت تأثیر فناوری، نوسانات جهانی، هزینه‌های کارگری و سرمایه‌های موجود است. در این تحقیق، تیغه‌های FRP و فولادی معمولی برای دستگاه‌های ساختاری گاوآهن قلمی به‌طور مداوم استفاده می‌شود. این تیغه‌ها از نظر اقتصادی و عملکردی در دسترس است و تولید شده و مصرف شده‌اند.

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واژه‌های کلیدی: تیغه کامپوزیت FRP، تیغه فولادی، زاویه حمله، سرعت پیشروی، میزان رطوبت خاک

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Workplace and Gravity: Two Mechanized Cow Milking Systems Compared for Human Physiological Strains

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Abstract

Despite the development of dairy farm mechanization, milking operations are still associated with heavy workloads which result in human physiological strains. This study investigated the role of gravity force in the linkage between load carriage and workers’ physiological strains in milking work tasks of two major cow milking systems (milking in stanchion barns and tandem parlors). These two milking methods similarly included washing the teats, attaching the cluster, and detaching the cluster. Human energy expenditure (EE) was calculated and load carriage direction in comparison with gravity (LCG) was tracked among twenty-four male workers. The highest heart rate (107 beats min⁻¹) and EE (35.5 kJ min⁻¹) were reported for attaching the cluster in the tandem parlor milking method. Tandem parlor milking caused higher human physiological strains and higher proportions of converse LCG compared with stanchion barn milking. By developing dairy farm mechanization from stanchion barn to tandem parlor, cow milking workers are induced to apply higher forces including converse LCG causing higher human physiological strains. Mechanization of dairy farms should be developed not only for improving the rate of work and performance but also for making conditions toward a reduction in the use of human physical forces.

Keywords: Energy expenditure, Load carriage, Stanchion barn, Tandem parlor

Introduction

Agricultural mechanization has been a key factor in improvement of performance and work speed in recent decades (Hasantabar et al., 2019). Meanwhile, occupational health issues have not been considered as wide as work speed and performance, and labor-intensive activities and ergonomic challenges are still prevalent among agricultural subsectors (Javidi Gharacheh and Khojastehpour, 2016; Gholami et al., 2017; Hayati et al., 2018a). Even, in some cases, farm workers suffer from ergonomic problems although they use farm machinery because these machines do not match properly with their operators’ anthropometric dimensions (Rostami et al., 2015). Dairy farm is one of the agricultural subsectors in which the workers are exposed to hazardous situations concerning occupational risk factors (Jakob and Rosecrance, 2018).

Dairy production was one of the first livestock operations that has been mechanized (Puckett, 1980). However, the stanchion milking method as a traditional one, in which the cows are tied up, is still a common cow milking method (Hayati et al., 2015a; Hayati et al., 2018b). The dairy farm production...
system, in both traditional and mechanized systems, involves many of the work tasks associated with risk factors such as repetitive and forceful movements, awkward postures and load carriage (Nemeth et al., 1990; Ahonen et al., 1990; Hayati et al., 2015b). Employees within dairy farm activities, regularly work with heavy loads. The continuous load carriage is accounted for as a reason for low back pain and joint degeneration and elevating the risk of muscle fatigue and injury, and the physiological strains of activities will be higher when carrying the load (Taylor et al., 2016).

Physiological-based studies addressed the ergonomic problems in milking systems and partly investigated the workplace design and equipment as the effective factors in the milking operations. For example, the effects of working height, and vertical and horizontal distances between the worker and the cow on muscular and energy loads (Vos, 1974; Nemeth et al., 1990) and a decline in cardiorespiratory loads by installing automatic milking units (Perkiö-Mäkelä and Hentilä, 2005) were introduced as physiological issues related to the milking operation workplace. However, the role of gravity through the variations of human physiological strains in dairy farms has still not been investigated.

Gravity and human physiological strains were studied in some areas. Studies about relationships among equipment design, gravity, and physiological strains suggested that loads carried close to the body’s center of gravity exert the least physiological strain (Taylor et al., 2016). Physiological strains applied to the climbing workers of traditional date fruit harvesting were affected when changing the approximate angle between their moving direction and gravity force (Marzban and Hayati, 2018). These were some studies about the linkage between load carriage and physiological strain in various areas, which could be considered in the dairy farm area. Lack of such studies in the dairy farm area encouraged us to investigate the role of gravity in the linkage between load carriage and workers’ physiological strains in cow milking work tasks.

Materials and Methods

Milk methods and work tasks

Milking in a stanchion barn (a type of tethering system) and milking in a tandem parlor (a type of loose-housing system), as two major methods, were considered in the present study (Fig.1). Tandem parlor milking is more mechanized than the stanchion one. Work tasks of stanchion and tandem milking systems were similarly “washing the teats”, “attaching the cluster” and “detaching the cluster”.

Fig.1. A stanchion barn (a) and a tandem parlor (b)

Workers were instructed to perform given job tasks at the normal routine times. After familiarizing the worker with their instruction, work tasks’ cycle times were recorded using a stopwatch. Average cycle times in stanchion and tandem milking systems were 15.5 s and
9.75 s, respectively, for washing the teats, 15.25 s and 9.5 s for attaching the cluster, and 7 s and 4.75 s for detaching the cluster.

In washing the teats in the stanchion milking method, the worker takes a little water from a bucket full of water by a bowl and strews it on the teats in a squatting posture, and washes the teats associated with massaging the teats by the right hand. This work task is performed in the tandem method with the following manner: worker holds the water’s hose by the left hand in a standing posture as the cow is at a higher level than the worker and washes the teats associated with massaging the teats by the right hand. In attaching the cluster in both methods, the worker takes the cluster from its hook, carries, and installs it on the teats. Detaching the cluster was performed as follows: the cluster is uninstalled from teats, carried, and put on its hook. Attaching and detaching the cluster were carried out with walking and standing postures in the tandem parlor and with stooping and squatting postures in the stanchion barn.

A cluster, in both milking methods, weighed about 2.6 kg, which consisted of a claw piece and four liners, shells, short milk tubes, and short pulsation tubes. The mass of a part of a long milk tube, a part of a long pulsation tube, water’s bowl, and hose borne by hands was considered negligible.

**Participants**

Twelve male workers in stanchion barn and twelve male workers in tandem parlor whose job is milking, participated in this study (Table 1). They had no musculoskeletal symptoms, no medication, and at least two years’ job experience. They were right-handed and had full consent to take part in this study. Three workers of stanchion barns and three workers of tandem parlors were overweight and the rest of them were in the normal range based on body mass index (Pizzol et al., 2020).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Stanchion barn</th>
<th>Tandem parlor</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Gender</td>
<td>Male</td>
<td>Male</td>
</tr>
<tr>
<td>Age (year)</td>
<td>32.3 (±4.5)</td>
<td>37 (±3.6)</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.71 (±0.06)</td>
<td>1.78 (±0.05)</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>69 (±3.5)</td>
<td>78.7 (±2.3)</td>
</tr>
<tr>
<td>Body mass index (kg m⁻²) *</td>
<td>23.7 (±2.1)</td>
<td>24.6 (±2.3)</td>
</tr>
</tbody>
</table>

*Body mass index=Mass/(Height)²* (Pizzol et al., 2020).

**Physiological strains**

Heart rate, heart rate range (HRR), rate of perceived exertion (RPE), and human energy expenditure in physical activity (EE) were used to evaluate physiological strains (Table 2). Heart rate was measured by a Beurer PM 45 heart rate monitor (Beurer, Germany). The signals were transferred from the Beurer transmitter, put on the chest, to the heart rate monitor, put on the wrist. Data were recorded in temperatures between 36°C and 41°C. Physiological indexes were measured (or calculated) eight times for each participant in each work task. Means of physiological indexes were entered in statistical analysis.

**Tracking the direction of load carriage in comparison with gravity**

Work tasks were videotaped by a camera to track the load carriage direction in comparison with the force of gravity (LCG). LCG was classified into three major categories as follows: similar LCG: load carriage and force of gravity are in a similar direction (SLCG); converse LCG: load carriage and force of gravity are in the converse directions (CLCG); and orthogonal LCG: load carriage, in comparison with the force of gravity, is in an orthogonal direction (OLCG) (Fig.2). Each second was divided into four parts to increase the precision of video analysis. A skilled observer analyzed the videos. Data were collected with visual observation. Observational methods are reliable and valid for identifying potentially hazardous occupational jobs (Lowe et al., 2019). The average height level difference between hook and cow teats (Fig.1) in stanchion barns and tandem parlor was approximately measured as
0.36 m and 0.25 m, respectively. Videos were recorded for each participant with three repetitions and means of LCG values were represented. Means of LCG values were considered for statistical analysis.

<table>
<thead>
<tr>
<th>Table 2 - Indexes used to evaluate the physiological strains</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Index</strong></td>
</tr>
<tr>
<td>HR (heart rate at work)</td>
</tr>
<tr>
<td>HRR (heart rate range)</td>
</tr>
<tr>
<td>HR_{\text{rest}} (heart rate at rest)</td>
</tr>
<tr>
<td>HR_{\text{max}} (maximal heart rate)</td>
</tr>
<tr>
<td>RPE (rate of perceived exertion)</td>
</tr>
<tr>
<td>EE (the energy expenditure in physical activity)</td>
</tr>
</tbody>
</table>

* References used: HRR (Claessen et al., 2019), HR_{\text{rest}} (Montes et al., 2019), HR_{\text{max}} (Póvoas et al., 2020), RPE (Garzon and Comtois, 2020), EE (Chang et al., 2020).

Fig. 2. Load carriage directions (ranges shown with grey color) in comparison with the gravity (a: similar LCG; b: converse LCG; c: orthogonal LCG)

**Statistical analysis**

The data handling was carried out using IBM SPSS Statistics 24 (IBM Corporation, US). Before doing statistical analysis, the normality of the data was checked and confirmed. ANOVA, Duncan’s test, and independent samples t-test were used to compare the group mean related to the physiological indexes. Overall and partial proportions of SLCG, CLCG, and OLCG in each work task in each milking method were compared with their corresponding value in the other work tasks of that milking method using ANOVA and Duncan’s test and were compared with their corresponding value in the corresponding work task of other milking method using independent samples t-test. A value of \( p<0.05 \) (two-tailed) was regarded as statistically significant. A completely randomized design (CRD) was used to examine the groups with twelve repetitions (equal to the number of participants in each milking method) for each treatment. Treatments were the work tasks in ANOVA and were the milking methods in independent samples t-test. In the case of three categories of LCG, only where it was a necessity to reinforce the “results and discussion” section, categories with significant differences were mentioned and used. Regression analysis was conducted to validate the RPE-HR relationship and to investigate the predictor factors on EE. Values of milking methods were considered as a dichotomy (tandem method=1 and stanchion milking=0) in EE regression. Values of the
LCG have been presented as means based on the percent of the work task’s cycle time.

**Procedure**

After evaluating physiological strains and tracking LCG, the role of gravity in the linkage between load carriage and workers’ physiological strains in milking work tasks was descriptively discussed. Through conducting this study, validation of Borg scale based on heart rate, and linkage between milking methods and some physiological indexes were investigated.

**Results and Discussion**

**Physiological strains**

Table 3 and Table 4 show the results of ANOVA and comparison of means in terms of physiological strains. A significant difference was between the stanchion and tandem milking methods concerning each of work tasks and physiological indexes (HR, HRR, RPE, and EE). Significant differences were observed among work tasks of each milking method in the case of physiological indexes except for comparisons between washing the teats and detaching the cluster regarding HR, HRR, and EE in the stanchion method.

The heart rate is one of the important factors for workload indication (Manjarres et al., 2020). According to categorizing the workloads from “light work” to “extremely heavy work” based on heart rate (Astrand and Rodahl, 1986), both stanchion and tandem milking methods were classified in “moderate work”. This result also supports those of other researchers (Perkiö-Mäkelä and Hentilä, 2005) who reported that the milking operation is a “moderate job” in a dairy farm. The present study introduced the tandem parlor to be higher than the stanchion barn regarding HR.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Source of variance</th>
<th>Degree of freedom</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>**</td>
</tr>
<tr>
<td>HR</td>
<td>Stanchion barn</td>
<td>Treatment</td>
<td>2</td>
<td>51.63</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Error</td>
<td>33</td>
<td>3.23</td>
</tr>
<tr>
<td></td>
<td>Tandem parlor</td>
<td>Treatment</td>
<td>2</td>
<td>480.13</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Error</td>
<td>33</td>
<td>3.114</td>
</tr>
<tr>
<td>HRR</td>
<td>Stanchion barn</td>
<td>Treatment</td>
<td>2</td>
<td>37.68</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Error</td>
<td>33</td>
<td>2.19</td>
</tr>
<tr>
<td></td>
<td>Tandem parlor</td>
<td>Treatment</td>
<td>2</td>
<td>369.88</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Error</td>
<td>33</td>
<td>1.76</td>
</tr>
<tr>
<td>EE</td>
<td>Stanchion barn</td>
<td>Treatment</td>
<td>2</td>
<td>23.38</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Error</td>
<td>33</td>
<td>0.67</td>
</tr>
<tr>
<td></td>
<td>Tandem parlor</td>
<td>Treatment</td>
<td>2</td>
<td>190.65</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Error</td>
<td>33</td>
<td>0.67</td>
</tr>
</tbody>
</table>

Note: ** refer to significant differences at level 0.01.

**Table 4** - Physiological strains in milking methods

<table>
<thead>
<tr>
<th>Variables</th>
<th>Washing the teats</th>
<th>Attaching the cluster</th>
<th>Detaching the cluster</th>
<th>Average*</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR (bpm)</td>
<td>Stanchion barn</td>
<td>90.7 (±1.2)</td>
<td>94.6 (±1.5)</td>
<td>91.3 (±2.5)</td>
</tr>
<tr>
<td></td>
<td>Tandem parlor</td>
<td>100.7 (±1.2)</td>
<td>107.0 (±1.5)</td>
<td>94.3 (±2.5)</td>
</tr>
<tr>
<td>HRR (%)</td>
<td>Stanchion barn</td>
<td>23.0 (±2.2)</td>
<td>26.2 (±0.5)</td>
<td>23.2 (±1.2)</td>
</tr>
<tr>
<td></td>
<td>Tandem parlor</td>
<td>31.6 (±2.2)</td>
<td>36.4 (±0.5)</td>
<td>25.6 (±1.2)</td>
</tr>
<tr>
<td>RPE</td>
<td>Stanchion barn</td>
<td>10.5 (±0.8)</td>
<td>10.5 (±0.8)</td>
<td>10.5 (±0.8)</td>
</tr>
<tr>
<td></td>
<td>Tandem parlor</td>
<td>11.5 (±0.6)</td>
<td>11.5 (±0.6)</td>
<td>11.5 (±0.6)</td>
</tr>
<tr>
<td>EE (kJ min⁻¹)</td>
<td>Stanchion barn</td>
<td>22.3 (±0.9)</td>
<td>24.9 (±0.3)</td>
<td>22.6 (±1.4)</td>
</tr>
<tr>
<td></td>
<td>Tandem parlor</td>
<td>31.5 (±0.6)</td>
<td>35.5 (±1.2)</td>
<td>27.5 (±0.6)</td>
</tr>
</tbody>
</table>

* Refer to the weighted arithmetic mean of three work tasks according to their cycle times.

This result resembles other studies where HR during the milking in parlors (97 bpm) (Perkiö-Mäkelä and Hentilä, 2005) was higher than HR in tie-stall milking (89 bpm) (Ahonen et al., 1990) for men. Therefore, it can assume that milking in tandem systems is heavier than
milking in stanchion ones for men which was in the inverse of the result revealed by Perkiö-Mäkelä and Hentilä (2005) for women. It may be due to the fact that walking in the tandem milking method constrains worker to have a higher physiological exertion in the present study.

The linear regression analysis to validate RPE-HR linkage in milking operation extracted a significant relationship (p-value <0.00) between HR and RPE as the following equation: \( RPE = 0.095 \times HR + 1.1552 \) (Adjusted \( R^2 = 0.644 \)). This equation showed that by increasing the heart rate at a work, the perceived exertion of the worker to carry out that work increases. The present study was supported by other studies in which the Borg scale was introduced as valid and reliable for identifying the relationship between heart rate and rate of perceived exertion (Cabral et al., 2020; Williams, 2017; Penko et al., 2017).

Linear regression was also established including EE as the dependent variable, and HR and milking methods as the independent variables (Table 5). HR variations could not explain the EE variation, but milking methods did. The regression showed that the utilization of the tandem milking method, in comparison with the stanchion method, increased the EE by 6.265 units (kJ min\(^{-1}\)). The improvement of the mechanization level caused an increase in energy expenditure (Table 5). Indeed, it forced upon the worker to have more walking and standing during work cycle time more than the less mechanized method (stanchion method) which may be rationally accepted as a reason for increased EE. However, it decreased the time taken to perform work tasks. It highlights the addressing worker's health and comfort, besides the worker's rate of work improvement through technology development (Almassi et al., 2014).

### Table 5- Regression established with the dependent variable of energy expenditure (EE)

<table>
<thead>
<tr>
<th>Variables</th>
<th>B</th>
<th>Standardized B</th>
<th>t</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>23.539</td>
<td>21.726</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Heart Rate (HR)</td>
<td>-0.003</td>
<td>-0.225</td>
<td>0.823</td>
<td></td>
</tr>
<tr>
<td>Milking method</td>
<td>6.265</td>
<td>7.352</td>
<td>0.000</td>
<td></td>
</tr>
</tbody>
</table>

Model summary: \( R^2 = 0.664; \) Adjusted \( R^2 = 0.441; \) \( F = 27.235; \) \( p\)-value: <0.000

In the present study, load (cluster) carried by workers of stanchion and tandem milking methods was approximately 3.5% of their mean body mass. Some studies reported that although HR was not significantly affected by load mass (0%, 20%, 30%, and 40% of body mass), RPE was significantly affected by increasing load mass and distance (Simpson et al., 2011). Others reported increased heart rate and RPE with increasing load from 0% to 50% body mass (Gordon, et al., 1983). In these studies and similar former studies increased load units were often equal to or over 10% of body mass. It seems partly improbable that a load of 3.5% body mass significantly affects physiological strains in the present study. But, regarding the studied milking methods, load carriages were often performed by hands in milking operations, and among four load carriage methods (rucksack, low back, across the shoulder, and in the hand), maximum physiological strains were found for load carriage by hand, besides earlier fatigue and bending of the body and deformity in posture (Malhotra and Gupta, 1965). Workers of our study may not be exempt from these risk factors. In mentioned studies (Gordon, 1983; Simpson et al., 2011), loads were often carried by a body part rather than hands, so the difference in physiological-based results respecting load carriage was acceptable based on the findings of another study (Malhotra and Gupta, 1965). However, it may be an interesting case for further studies to investigate various load carriage methods with various weights in cow milking operations.

**The role of gravity in the linkage between load carriage and physiological strains**

Table 6 and Table 7 show the results of ANOVA and comparison of means in terms of tracking the LCG. At the detaching cluster, the
proportion of converse position in the tandem parlor (50%) was significantly higher than that in the stanchion barn (11%+12%) (p<0.00). In general, findings of applied physiology studies imply that physiological strains to do work including CLCG are higher compared with those including OLCG. Also, physiological strains to do work including OLCG are higher compared with those including SLCG (Brubaker et al., 1986; Minetti et al., 2002; Abe et al., 2008). Based on this rule, we discussed the workers’ physiological strains as follows:

Table 6- Results of ANOVA among work tasks of milking methods with reference to LCG classification

<table>
<thead>
<tr>
<th>Variable</th>
<th>Source of variance</th>
<th>Degree of freedom</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLCG</td>
<td>Stanchion barn</td>
<td>Treatment</td>
<td>2</td>
<td>775.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Error</td>
<td>33</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Tandem parlor</td>
<td>Treatment</td>
<td>2</td>
<td>4853.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Error</td>
<td>33</td>
<td>0.4</td>
</tr>
<tr>
<td>CLCG</td>
<td>Stanchion barn</td>
<td>Treatment</td>
<td>2</td>
<td>20642.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Error</td>
<td>33</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>Tandem parlor</td>
<td>Treatment</td>
<td>2</td>
<td>16151.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Error</td>
<td>33</td>
<td>2.9</td>
</tr>
<tr>
<td>OLCG</td>
<td>Stanchion barn</td>
<td>Treatment</td>
<td>2</td>
<td>29683.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Error</td>
<td>33</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>Tandem parlor</td>
<td>Treatment</td>
<td>2</td>
<td>21732.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Error</td>
<td>33</td>
<td>1.480</td>
</tr>
</tbody>
</table>

Note: ** refer to significant differences at level of 0.01.

Table 7- Proportions (%) of the direction of load carriage in comparison with the force of gravity based on work tasks’ cycle times*

<table>
<thead>
<tr>
<th>Work tasks</th>
<th>Washing the teats</th>
<th>Attaching the cluster</th>
<th>Detaching the cluster</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion</td>
<td>100%</td>
<td>16%</td>
<td>81%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11%</td>
<td>71%</td>
</tr>
<tr>
<td>Stanchion barn</td>
<td>Direction of load carriage in the order of appearance</td>
<td>⤷</td>
<td>⤷</td>
</tr>
<tr>
<td>Proportion</td>
<td>11%</td>
<td>89%</td>
<td>16%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>19%</td>
<td>65%</td>
</tr>
<tr>
<td>Tandem parlor</td>
<td>Direction of load carriage in the order of appearance</td>
<td>⤷</td>
<td>⤷</td>
</tr>
<tr>
<td>Proportion</td>
<td>50%</td>
<td>35%</td>
<td>15%</td>
</tr>
</tbody>
</table>

*Legend: ⤷ and ⤷ refer to similar, converse, and orthogonal LCGs (SLCG, CLCG, and OLCG) respectively.

In both milking methods, physiological strains (except RPE) for attaching the cluster were found to be higher than detaching the cluster. Based on the aforementioned studies, the increase in these indexes may be partly affected by the gravity effects (the mass of clusters). In attaching the cluster, the worker expended a considerable physiological effort to maintain the cluster at a constant height by applying the force converse of gravity with one hand. Simultaneously, the other hand was occupied to install the cluster’s liners on the teats. This occupied a major proportion of cycle time in attaching the cluster in stanchion barns (81%) and tandem parlor (65%) (Table 7). In both methods, during detaching the
cluster, the worker maintained the cluster with one hand and uninstalled the liners with another hand. This also induced applying the force converse of gravity to maintain the cluster. According to Table 7, proportions shown for uninstalling liners were lower than those of installing the liners in both stanchion barns (81%>11%) and tandem parlor (65%>50%). It could be the main reason for the increase in physiological strains in attaching the cluster compared with detaching the cluster in both methods.

The comparison between milking methods could address the effect of the workplace. The workplace design of the tandem parlor had major differences from that of the stanchion barn. The height level of the cluster hook was lower than cow teats in the tandem parlors, whereas, the inverse of this condition was established in the stanchion barn (Fig.1). Therefore, the workplace design of the tandem parlor induced the worker to carry the cluster from its hook (16%) and lift it to a higher level (cow teats) by applying a force converse of gravity (19%). But in stanchion barn worker carried it while changing his posture from stooping to squatting (declining work height, 16%) and moved it toward cow teats at the same height level (3%). These, in addition to installing cluster’s liners (81% and 65% in stanchion barn and tandem parlor respectively), implied that during attaching the cluster, workers bore higher physiological strains in tandem parlor compared with stanchion barn.

Although, detaching the cluster was partly performed in an inverse order compared with attaching the cluster, LCGs of this operation were not in the inverse order of that of attaching the cluster. In the stanchion barn, in the work task of detaching the cluster, as shown in Table 7, the worker uninstalled the cluster’s liners (11%), brought it down in a similar direction with gravity (6%), carried it toward milking machine (71%) and changed squatting posture to stooping posture to bring the cluster to the height level of the hook (12%). Uninstalling the cluster’s liners in the tandem parlor (50%) induced to apply a more converse LCG (50%>11%+12). Then, the worker carried the cluster downward (35%) and toward hook (15%) in the tandem parlor. Results implied that perhaps the most important reason for the increase in physiological strains in tandem parlor compared with stanchion barn during detaching the cluster is more clearly expressed by considering the CLCG in the tandem parlor (50%) and stanchion barn (11%+12%=23%).

The present study showed “it is discussable that some factors, which have not been addressed yet, may affect physiological strains in dairy farms such as the force of gravity”. Our study did not decide to generalize the effect of gravity as the absolute factor affecting physiological strains in all cases. Some other factors may also affect the physiological strains in dairy farm activities. For example, working posture is an important factor in the variation in physiological strains. In this case, former researchers reported that more walking was an explanation for increasing HR from women to men during milking (Perkiö-Mäkelä and Hentilä, 2005). The work habits of the worker may also contribute to the physiological strains in dairy farm activities, as a strong matter in ergonomic issues, which is not easily changed (Nevala-Puranen, 1995). Besides, the impact of any load is not just a function of its mass, but its dimensions and distribution around the body which could affect the body’s center of gravity and finally affect physiological strains (Taylor et al., 2016). Overall, it could be said that probably several factors (e.g. gravity, working postures, and body’s center of gravity) could simultaneously affect the human physiological strains in milking work tasks in dairy farms. Further studies would be undertaken to illuminate these cases.

**Limitations**

This study was undertaken by employing the male gender only. If women took part in this study, findings could be more generalizable.

**Conclusion**

The present study showed that by developing dairy farm mechanization from
stanchion barn to tandem parlor, during cow milking, workers are induced to apply higher forces converse of gravity which causes higher human physiological strains as one of the occupational health challenges. It had been shown that the force of gravity affects human physiological strains. Simultaneously, other factors may also affect human physiological strains. Therefore, the mechanization of dairy farms should be developed not only for improving the rate of work and performance but also for making conditions toward a reduction in the use of human physical forces.

Acknowledgment

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References


مقایسه فشارهای فیزیولوژیکی انسانی در دو روش مکانیزه شیردوشی گاو شیری با تأکید بر محیط کار و گرانش زمین

عبد الله حیات ۱، افشین مرزبان ۲*، محمد امین آسودار ۳

چکیده
با وجود توسعه مکانیزاسیون دامداری‌های گاو شیری، هنوز هم فعالیت‌های شیردوشی همراه با فشارهای کاری سنگین باشد که باعث بروز فشارهای فیزیولوژیکی روی نیروی کار می‌شود. در این مطالعه، تأکید بر تأثیرات بین حمل بار و فشارهای فیزیولوژیکی در وظایف کاری دو سیستم عمده شیردوشی گاو شیری شامل شیردوشی در جایگاه‌های استاندارد و سالن‌های تاندم مورد بررسی قرار گرفت. این دو روش مربوط به مشاهده شرکت کردن نیروی کار در زمینه کار و فشارهای فیزیولوژیکی در وظایف کاری می‌شود. در مقایسه با نیروی گرانش در سالن‌های تاندم، با توجه به نیروی کار کاهش، افزایش در حمل بار جهت نیروی کار می‌شود. در نهایت، این روش در مقایسه با روش شیردوشی استاندارد باعث اعمال فشارهای فیزیولوژیکی بالاتری در وظایف کاری می‌شود. در کل، این روش در مقایسه با روش شیردوشی استاندارد باعث تفاوت باعث اعمال فشارهای فیزیولوژیکی بالاتری در وظایف کاری می‌شود.

واژه‌های کلیدی: انرژی مصرف، حمل بار، شیردوشی استاندارد، شیردوشی سالن‌های تاندم

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Abstract

The main aim of this study was to optimize the design parameters of the fruit shakers for efficient harvesting of Shengy olive. A single-degree-of-freedom spring-mass model was established to determine the natural frequency and damping coefficient of the limb. A tractor-mounted shaker that transmits vibration to limbs and fruits via a reciprocating mechanism was fabricated for field evaluation of the forced vibration modes. A 3×4 factorial experiment with a completely randomized design was conducted to investigate the effects of shaking amplitudes and frequencies on fruit removal. The shaking mode with a frequency of 10 Hz and amplitude of 80 mm transmitted the average power of 92 W to remove 95% of fruits in the field trial. This oscillation characteristic should be used to redesign the fruit shakers to pass human safety standards and efficient harvesting.

Keywords: Fruit harvester, Forced vibration, Limb shaker, Mathematical modeling, Natural frequency

Introduction

Fruit shakers shake the trunk or branches or have contact heads with rods that extend into the canopy (Giametta and Bernardi, 2010; Lavee, 2010; Ravetti and Robb, 2010; Sarri and Vieri, 2010; Tous et al., 2010; Vieri and Sarri, 2010; Sola-Guirado et al., 2014; Moreno et al., 2015; Sola-Guirado et al., 2016; Zhang et al., 2016; Sola-Guirado et al., 2018; Peça et al., 2019). Frequency and amplitude are among the principal operating parameters of the shakers concerning humans, trees, and fruit (El Attar et al., 2004; Blanco-Roldán et al., 2009; Zhou et al., 2013; He et al., 2017a). Due to the damage of high frequency on humans, the manufacturers must declare the acceleration value in the machine instruction manual (Saraçoğlu et al., 2011; Deboli et al., 2014a). However, manufacturers of shakers do not often know which variety of their machines will be used on; therefore, they design shakers with fixed acceleration and frequency values leaving the operators the responsibility of choosing the suitable shaking mode (Costa et al., 2013).

Modal testing is one of the best tools for the dynamic characterization of the fruit shakers (Crooke and Rand, 1969; Tsatsarelis, 1987; Amirante et al., 2007; García et al., 2007; Castro-García et al., 2008; Torregrosa et al., 2014). Recording accelerations of fruits or limbs in response to applied vibration modes by accelerometers (Torregrosa et al., 2009; Du et al., 2012; Bentaher et al., 2013) and modeling of the vibration system by a mass-spring model (Gupta et al., 2015; Du et al., 2020; Chen et al., 2021) were tried for analyzing vibration mode and redesigning of mechanical fruit shakers. Natural frequency, damping ratio, and transmitted power are the important oscillation factors for the redesign of the mechanical fruit harvesters.

The main objective of this study is to identify an effective oscillating mode of the Shengy olive limbs useful for the redesign of mechanical harvesters. Mathematical modeling of the single-degree-of-freedom system
provides the vibration mode for olive shakers concerning fruit removal efficiency and human safety standard levels.

**Materials and Methods**

**Mathematical modeling**

A limb consists of the limb, fruits, and leaves. The sinusoidal force applied on the spring-mass system of the limb by the shaker produces acceleration which depends on the spring rate and damper constant. Newton’s Second Law for representing the limb behavior in response to an external harmonic force gives the equation of motion.

\[
m\ddot{x}(t) + c\dot{x}(t) + kx(t) = f\cos(\omega t)
\]

(1)

where \(m\), \(f\), \(c\), \(k\), \(\omega\), and \(\alpha\) are the mass (kg), the applied force (N), the damping coefficient (kg s\(^{-1}\)), the spring rate (N m\(^{-1}\)), the circular frequency of the system (Rad s\(^{-1}\)), the amplitude (m), and the phase angle (Rad), respectively. The displacement of mass \(M\) at time \(t\) is \(x(t)\).

Replacing of (2) through (4) in (1) yields.

\[
\frac{\ddot{x}(t)}{\ddot{x}(t)}\left[(-m\omega^2 + k)\cos(\omega t - \alpha) - c\omega\sin(\omega t - \alpha)\right] = \frac{f\cos(\omega t)}{F(t)}
\]

(5)

and by setting \(t = 0\), one could re-write (5) as:

\[
\frac{\ddot{x}(t)}{\ddot{x}(t)}\left[(-m\omega^2 + k)\cos(\alpha) + c\omega\sin(\alpha)\right] = F
\]

(6)

The amplitude of the force vector \(F\) in (6) defines as:

\[
\frac{\ddot{x}(t)}{\ddot{x}(t)}\left[(-m\omega^2 + k)^2 + c^2\omega^2\right]^{\frac{1}{2}} = |F|
\]

(7)

Using the notation of \(F\) in (5), the power \(P\) can be calculated by:

\[
P(t) = \frac{|F(t)|\cos(\omega t)}{|F(t)|\cos(\omega t)}\times V(t)
\]

(8)

Replacing (7) in (8) using the definition of (3) yields.

\[
\left(-\frac{\ddot{x}(t)}{\ddot{x}(t)}\right)\omega^2[(k - m\omega^2)^2 + c^2\omega^2]\cos(\omega t)\sin(\omega t - \alpha)
\]

(9)

By setting the derivative of (9), in respect to \(t\), to zero, the maximum required power could be represented by:

\[
\frac{dP}{dt} = \left(-\frac{\ddot{x}(t)}{\ddot{x}(t)}\right)\omega[(k - m\omega^2)^2 + c^2\omega^2]\sin(\omega t)\sin(\omega t - \alpha) + c^2\omega^2|\sin(\omega t)\sin(\omega t - \alpha)| = 0
\]

(10)

Which implies:

\[
cos(\omega t)\sin(\omega t - \alpha) - \sin(\omega t)\sin(\omega t - \alpha) = 0 \rightarrow \frac{\pi}{2} - \frac{\pi}{2} = \frac{\pi}{2}
\]

(11)

By replacing (11) in (9), one could write the maximum power in the final form of:

\[
P_{\text{max}} = \frac{\left(-\frac{\ddot{x}(t)}{\ddot{x}(t)}\right)\omega[(k - m\omega^2)^2 + c^2\omega^2]}{8}\]

(12)

Furthermore, the average power can be calculated as:

\[
P_{\text{av}} = \sum \left(\frac{P(t)}{T_f}\right) = \frac{1}{T_f}\int_0^T p\,dt
\]

(13)

and by replacing (9) in (13), one has that:
In which the phase angle ($\alpha$) can be calculated by (Dimarogonas, 1976; Blevins, 2015):

$$\alpha = \tan^{-1} \frac{2\zeta \left( \frac{\omega_n}{\omega} \right) \left( 1 - \zeta \left( \frac{\omega}{\omega_n} \right) \right)^{1/2}}{1 - \zeta \left( \frac{\omega}{\omega_n} \right)^2}$$  \hspace{1cm} (15)

Where,

$$\omega_n = \left( \frac{k}{m} - \frac{c^2}{4m^2} \right)^{1/2}$$ \hspace{1cm} (16)

and

$$\zeta = \frac{c}{2m\omega_n}$$ \hspace{1cm} (17)

By replacing (16) in (17), one could define the natural frequency, $\omega_n$, as:

$$\omega_n^2 = \frac{k}{m(1+\zeta^2)}$$ \hspace{1cm} (18)

In (15) $\omega$ and $\zeta$ are the circular frequency of the system (Rad s$^{-1}$), and the damping ratio of the limb, respectively.

**Experimental area and layout**

A limb shaker was designed and fabricated to oscillate the limbs with different vibration modes (Fig.2a). The tractor-mounted fruit harvester received its power from the power take-off (PTO) shaft and transmitted it to the tree limb through a boom and a special clamping device (Fig.2b). A V-belt drive system changed the initial 540 revolutions per minute (rpm), supplied by the standard tractor PTO shaft, to 200-1200 rpm and corresponding frequency ranging from 3.2 to 20 Hz. Five levels of shaking amplitude (4, 6, 8, 10, 12 cm) were provided by a slider-crank mechanism, where rotating motion was converted to a reciprocating motion. The clamping device is a quick fastening type equipped with a soft pad as an intermediate media for the protection of the bark. The machine's overall dimensions are 140×80×100 cm. The machine seats on the ground utilizing a hydraulic system of the tractor.

![Fig.2. a) Fabricated limb shaker during evaluation in the orchard, b) clamping device with soft pad attached to limb for vibration cushioning.](image)

The experiments were performed in the Bash Garden in Shiraz (29° N latitude and 52° E longitude), Iran. A 3x4 factorial experiment with a completely randomized design with three replications was conducted to investigate the effect of shaking amplitude and frequency on fruit detachment of green (unripe) Shengy olives. Three levels of oscillating frequency (10, 14, and 20 Hz) and four levels of shaking amplitude (40, 60, 80, and 100 mm) were investigated. According to Rezaei et al. (2016), the duration of vibrations for trials was fixed at 5 s. The circular frequency was measured by a light tachometer on the slider-crank mechanism.

Before fruit harvesting, a sheet was spread under the tree. The mechanically removed fruits and fruits remaining on the branch (picked manually) were weighed separately to
determine harvesting efficiency. The fruit removal percentage is:
\[ e = \frac{w_a}{w_a + w_b} \times 100 \]  
(19)

Where \( e \) is the fruit harvesting percentage (%), \( w_a \) is the weight of fruits harvested from each branch, \( w_b \) is the weight of fruits remained on each branch.

The damages to the tree were not considered here. The method of determining damages that comprised of the leaves which were detached from the tree and fallen on the ground, the bark injured by the clamping device, and broken small stems with some leaves presented by (Chen et al., 2012; Gambella et al., 2013; Kargarpour et al., 2018; Memari et al., 2019).

Results and Discussions

The effects of shaking frequency and amplitude were both significant on fruit detachment, while no interacting effect was observed (Table 1). Figure 3 shows the comparison between mean values of detached fruits (%) from limb for different amplitudes and frequencies at 5% significance level. The oscillation mode with a shaking frequency of 10 Hz and amplitude of 80 mm, which caused 95% fruit detachment, passes the standard level of daily vibration dose of 11.4 Hz recommended by Aiello et al. (2019) where the damaging effect on the hand is reached. Oscillation of olive trees with a frequency of 24 Hz and amplitude of 60 mm (Sessiz and Özcan, 2006), 16 Hz and 100 mm (Rezai et al., 2015), 23 Hz and 100 mm (Babanatsas et al., 2018), 22–27 Hz (Leone et al., 2015), 35 Hz and 25 mm, and 25 Hz and 25 mm (Alzoheiry et al., 2020), 41 Hz and 25 mm, and 17 Hz and 100 mm (Ferguson et al., 2010) have significant differences with the recommended frequency in this research. The low ratio of the weight of the fabricated machine (120 kg) to the limb weight (8 kg) couple them as an oscillating system. However, in tree shakers i.e., (Pellenc, 2019; Solano, 2020) the large mass of the machine avoids coupling the machine with the tree.

Table 1- Analysis of variance of the percentage of detached fruits for different configurations of amplitude and frequency

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Degrees of freedom</th>
<th>Sum of squares</th>
<th>Mean square</th>
<th>FS</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replication</td>
<td>2</td>
<td>0.172</td>
<td>0.08</td>
<td>0.0044</td>
<td></td>
</tr>
<tr>
<td>Amplitude</td>
<td>3</td>
<td>9459.80</td>
<td>3153.26</td>
<td>162.71</td>
<td>0.01</td>
</tr>
<tr>
<td>Frequency</td>
<td>2</td>
<td>480.62</td>
<td>240.31</td>
<td>12.35</td>
<td>0.01</td>
</tr>
<tr>
<td>Amplitude x frequency</td>
<td>6</td>
<td>245.41</td>
<td>40.90</td>
<td>2.10</td>
<td>ns</td>
</tr>
<tr>
<td>Error</td>
<td>22</td>
<td>427.75</td>
<td>19.44</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Fig.3](image_url) Percentage of detached fruits for different configurations of amplitude and frequency. The same letters do not have a significant difference with a probability of 5%.
By replacing the mean value of 13675 N m$^2$ of elasticity and 8 kg for the mass of a limb (Golpira, 1998), the damping ratio of 0.1 for olive limbs (Adrian et al., 1965; Hoshyarmanesh et al., 2017) in (18) the limb’s natural frequency (Hz).

$$\omega_n^2 = \frac{k}{m}(1 + \delta^2) = \frac{13675}{8}(1 + 0.1^2) = 41.31$$

According to (17), $c$ (kg s$^{-1}$) is

$$c = 2 \times 8 \times 41.31 \times 0.1 = 66.15 \quad (21)$$

By replacing the frequency of 10 Hz in (15) the phase angle is:

$$\alpha = \tan^{-1}\left(\frac{2 \times 10}{1 \times 41.31}\right) = 0.05 \quad (22)$$

The same reasoning to introduce the concept of electromechanical modes can be extended to interpret (20). Any torque imbalance may cause several electromechanical modes with different frequencies (Golpira et al., 2021). The exciting vibration of 10 Hz to the limb may produce a natural frequency of 41.31 Hz in olive fruits. Natural frequencies of 20.2 and 37.7 Hz (García et al., 2007), and 33.9, 31.9, and 28.0 Hz were calculated for olive limbs (Alzoheiry et al., 2020).

By substituting the amplitude of 0.08 (m) in (12) the maximum power is

$$P_{\text{max}} = -\left(\frac{0.08^2}{8}\right)10 \times 2 \times 3.14[(13675 - 8 \times (10 \times 2 \times 3.14)^2) + 66.15 \times 2 \times 3.14 \times 10]^\frac{1}{2}(1 - \sin0.05) = 1756 \quad (23)$$

By replacing the values of parameters in (14) the average power is

$$P_{\text{avg}} = \left(\frac{0.08^2}{4}\right)10[(13675 - 8 \times 10^2)^2 + 66.15 \times 2 \times 3.14 \times 10]^\frac{1}{2}(\sin0.05) = 92 \quad (24)$$

The lower amount of energy regards to the lower shaking frequency and amplitude transmitted to the system could result in the higher fruit collection (He et al., 2017b), lower tree damages (Gupta et al., 2016), and lower human damages (Çakmak et al., 2011; Deboli et al., 2014b).

**Conclusion**

This paper merged field experimental data of the olive limb shaking mode with the dynamic model of the spring-mass system to redesign the fruit harvesters. Mathematical modeling of the olive limb identified the natural frequency of 41.31 Hz with a damping coefficient of 66 kg s$^{-1}$. The single-degree-of-freedom model showed the maximum and average power of 1756 and 92 W for limb oscillation of Shengy olives. The free exposure to harmful hand-arm vibration mode with a working frequency of 10 Hz and an amplitude of 80 mm detached 95% of olives in the field trial. Modeling the coupling system of the limb and the machine with two unequal masses and springs can further improve the results.

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**References**


Nomenclature

c: Damping coefficient (kg s\(^{-1}\)), f: Force (N), F: Force vector, k: Spring constant (N m\(^{-1}\)), m: Mass (kg), \( P(t) \): Power (W), S: Amplitude (m), \( V(t) \): Velocity (m s\(^{-1}\)), t: Time of oscillation (s), x: Displacement of excitation (m), \( \dot{x} \): First derivative of the x (m s\(^{-1}\)), \( \ddot{x} \): Second derivative of the x (m s\(^{-2}\)), \( \omega \): Circular frequency (Rad s\(^{-1}\)), \( \omega_0 \): Natural frequency (Hz), \( \zeta \): Damping ratio, \( \alpha \): Phase angle (Rad)
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مطاله پژوهشی
جلد ۱۲، شماره ۱، بهار ۱۴۰۰، ص۱۸-۳۴

مد ارتعاشی موثر برای برداشت مکانیکی زیتون رقم شنگی
هیوا گلپیرا، محمد لغوی

چکیده
هدف از انجام این تحقیق بهینه‌سازی عوامل طراحی مашینهای برداشت مویه برای برداشت موثر زیتون رقم شنگی بود. مدل جرم-فنر با یک درجه آزادی برای تعیین سطح بسامد و ضریب میرایی شاخه زیتون استفاده شد. یک شاخه-کتان سوار که در ان ارتعاش از راه پاژی باید میگردد به شاخه و مویه انتقال می‌یابید. برای ارزیابی مقدار ارتعاش ساخه شد، به‌منظور تعیین تاثیر دامنه و بسامد ارتعاش بر میزان جداسازی مویه از شاخه یک آزمایش فاکتوریل (۳×۳) در قالب یک طرح کاملاً تصادفی اجرا شد. ذخیره مویه با بسامد ۱۰ هرتز و دامنه ۳۰ میلی‌متر توان متوسط ۸۳ درصد را برای برداشت ۹۵ درصد از مویهها انتقال داد. برای برداشت موثر و منطبق بر استانداردهای سلامتی مویه از طریق ارتعاشی درخت تکان‌های استفاده کرد.

واژه‌های کلیدی: ارتعاش، سطح بسامد، شاخه، کتان، ماشینهای برداشت مویه، مدل ریاضی

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Evaluating the Efficiency of Sugarcane Harvesting Units Using a Combined Approach to Data Envelopment Analysis and Data Mining

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Abstract

Every organization needs an evaluation system in order to be aware of the level of performance and desirability of its units. It is more important for agricultural companies, including agro-industries. In this study, 20 sugarcane harvesting units were selected. After modeling based on input-oriented CCR and BCC models, efficiency values for sugarcane harvesting units were calculated and the CART decision tree was used to extract rules to predict the efficiency of these units. The results of a study of 20 sugarcane harvesting units in the CCR model showed that 6 units had an efficient score and 14 units had an inefficient score, and their technical efficiency score was in the range of 0.73-0.95. The results of the BCC model study also showed that out of a total of 20 sugarcane harvesting units, 8 units had efficient scores. As can be seen, in the BCC model, more units are introduced as efficient units and there is less dispersion between inefficient units. Also, the distribution of efficient units in the BCC model is less than the CCR model. The average technical efficiency, pure technical efficiency, and scale efficiency were 93%, 88%, and 93%, respectively. Also, the accuracy of the decision tree model for technical efficiency and pure technical efficiency was 86% and 93%, respectively.

Keywords: CART, DEA, Harvest, Sugarcane

Introduction

Harvesting crops and transporting them from two dimensions has a great impact on sugarcane production and the income of an agro-industry. In terms of cost, which accounts for the majority of sugarcane production costs, and in terms of income, due to the amount of sugarcane waste at harvest time and the quality of the product sent to the factory and the amount of damage to the farm and sugarcane stump, it has a great impact on the amount of yield in the same year, ratooning^2 years and eventually agro-industry income. In Iran, sugarcane is industrially produced by Khuzestan Sugarcane and By-Products Development Company, Haft Tappeh, Karun and Mian Ab agro-industries (about 135,000 hectares). In these agro-industries, there are four harvesting groups for sugarcane harvesting operations. Each harvesting team consisted of six harvesters. There are four active and stationary in the group and two as reserve units. There are also 20 transporters and 24 drivers (mechanic operators) of the harvester and the transporter in each group, along with an expert in the group (one person), mechanic technician (2 persons), electricians (3 persons), and service workers (3 persons) are used.

Data envelopment analysis (DEA) model is a useful tool in measuring the efficiency of several organizational units with the same structure. In other words, the DEA model
minimizes the ratio of inputs to outputs. This study is an attempt to determine the efficiency of harvesting units located in sugarcane production companies to identify inefficient or less efficient units. On the other hand, due to the increase in data volume and the need to analyze information and predict variables, data mining, especially the decision tree, can be helpful. The decision tree is one of the data mining methods. A decision tree is a diagram that shows a classification system or a predictive model and is a way to display a series of rules that lead to a category or value (Jenhani et al., 2008). In recent years, a wide range of researchers in various fields have used DEA model, data mining model, and a combination of the two methods (Rahman et al., 2019; Liu et al., 2019; Li et al., 2018). Chiang et al. (2017) evaluated the performance of the information and communication technology (ICT) industry in Taiwan using a combination of DEA and decision tree and examined 16 relevant companies. Toloo et al. (2009), in a paper by using a combination of data mining and DEA evaluated different rules for evaluating performance. Wanke and Barros (2016) investigated the role of heterogeneity in the insurance sector. This study focused on predicting the performance of Brazilian insurance companies by proposing an integrative, two-stage approach, which involved the determination of a DEA meta-frontier in the first stage and the use of several data mining techniques in the second. Wu (2009) presented a hybrid model using DEA, decision trees, and neural networks (NNs) to assess supplier performance. The model consists of two modules: Module 1 applies DEA and classifies suppliers into efficient and inefficient clusters based on the resulting efficiency scores. Module 2 utilizes firm performance-related data to train decision trees, NNs model, and apply the trained decision tree model to new suppliers. Raoorane and Kulkarini (2012) discussed the role of data mining as an effective tool for yield estimation in the agricultural sector. As crop production depends on geographical, biological, political, and economic factors, data mining can solve the challenge of extracting knowledge from this raw data and estimate the amount of crops production. Ferraro et al. (2009) analyzed a large production database describing crop yield patterns. They studied the influence of several factors controlling sugarcane productivity in one of the most important areas of sugarcane production in Argentina. They proposed using a data mining technique called classification and regression tree (CART) to identify the dependence of sugarcane yield on the variation of both environmental and management factors. Ramesh and Vardhan (2013) predicted agricultural products yield using different data mining techniques such as K-Means, K-Nearest Neighbor, Support Vector Machines, and Artificial Neural Networks. They wanted to find a model with high accuracy and ability for prediction of the yield of agricultural products. Jeyseinthil et al. (2014) designed and predicted a support system for a database of sugarcane soil using the data mining clustering technique (k-means). Everinghama et al. (2009) in Australia and Fernandes et al. (2011) in Brazil have estimated the yield of sugarcane farms using data mining techniques. Medar and Rajpurohit (2014) presented various crop yield prediction methods using data mining techniques. Different Data Mining techniques such as K-Means, K-Nearest Neighbor (KNN), Artificial Neural Networks (ANN), and Support Vector Machines (SVM) for very recent applications of data mining techniques in the agriculture field.

This study examines how to evaluate the efficiency of sugarcane harvesting units using a combination of DEA and decision trees models and as a case study, sugarcane harvesting units in Amirkabir sugarcane agro-industry in Khuzestan province, Iran are considered. Because DEA evaluates the efficiency of harvesting units and a decision tree to predict their effectiveness, this research enables managers to use the results to improve performance in their future decisions.

Materials and Methods

Study area
The data for this study were collected from Amirkabir agro-industry Company of Khuzestan province in Iran. This agro-industry has 480 farms with 25.5 hectare area for each farm. It covers an area of about 14000 ha. Figure 1 shows the position of Khuzestan province in Iran and a map of Amirkabir agro-industry farms. The data is obtained for the years from 2015 to 2020. The study area is located in Khuzestan Province which is a major agricultural region in Iran. The geographical location of the study area is between latitudes 31° 15’ to 31° 40’ North, and longitudes 48° 12’ to 48° 30’ East. The average elevation of the study area is 8 m above sea level. Mean annual rainfall within the study area is 147.1 mm, mean annual temperature is approximately 25 °C, and mean soil temperature at 50 cm depth is 21.2 °C.

Fig.1. Amirkabir Agro-Industry position

Criteria for measuring the efficiency of sugarcane harvesting units

In this study, to measure the efficiency of sugarcane harvesting units and the best way to identify which unit has the best harvesting performance, nine indicators including the actual amount of hydraulic oil consumed during harvest after the overhaul of the harvester (litre), fuel consumption (litre), repair costs and the costs of consumable parts of harvesters (Rials), the amount of crop harvested (ton), harvest time (day), the amount of area harvested (hectare), factory no-cane hours, the amount of trash sent to the factory (percentage), and the amount of sugarcane waste on the farm (kilogram). To analyze the data, the DEA model has been used to measure the efficiency of sugarcane harvesting units, and the classification and regression trees (CART) model has been used in modeling and predicting the efficiency of these units. Software used also includes IBM SPSS MODELER 14.2 and DEA SOLVER. The research steps are shown in Figure 2.

Data envelopment analysis (DEA)

The DEA has four main models: Constant Return to Scale-CRS, Variable Return to Scale-VRS, Increase Return to Scale–IRS, and Decrease Return to Scale-DRS. Each of the above models has two directions of output-oriented and input-oriented (Liu et al., 2019). In DEA, an inefficient DMU can be made efficient either by reducing the input levels while holding the outputs constant (input-oriented); or symmetrically, by increasing the output levels while holding the inputs constant (output-oriented). Data analysis will be performed with two models CCR\(^1\) and BCC\(^2\). The CCR DEA model assumes constant

1- Charns, Cooper and Rhodes
2- Banker, Charns and Cooper
returns to scale. It measures the technical efficiency by which the DMUs are evaluated for their performance relative to other DMUs in a sample. On the other hand, the BCC DEA model assumes variable returns to scale conditions. Choosing the right DEA model depends on the level of control over the inputs and outputs; by making each one more controllable, the appropriate model is selected based on that. In this study, because the increase and decrease of inputs are more practical, CCR and BCC input-oriented models are used (Equations 1 and 2). In both models, efficient and inefficient units are identified and the types of technical efficiency, pure technical efficiency, and scale efficiency were calculated.

\[
\max E_p = \sum_{i=1}^{n} U_i Y_{ip} \\
\sum_{i=1}^{s} V_i X_{ip} = 1 \\
\sum_{i=1}^{r} U_i Y_{ij} - \sum_{i=1}^{s} V_i X_{ij} \leq \alpha, j = 1,2,\ldots,n \\
V_i \geq \varepsilon, U_i \geq \varepsilon
\]

(1)

\[
\max E_p = \sum_{i=1}^{n} U_i Y_{ip} + w \\
\sum_{i=1}^{s} V_i X_{ip} = 1 \\
\sum_{i=1}^{r} U_i Y_{ij} - \sum_{i=1}^{s} V_i X_{ij} + w \leq \alpha, j = 1,2,\ldots,n \\
U_i \geq \varepsilon, V_i \geq \varepsilon, w \text{ free}
\]

(2)

In the above Equations: \(j = 1,2,\ldots,n\), \(n\): the number of DMUs, \(s\): the number of outputs, \(m\): the number of inputs, \(X_{ij}\): the amount of input \(i^{th}\) for DMUp, \(Y_{ip}\): the amount of output \(r^{th}\) for DMUp, \(U_k\) and \(V_p\), respectively, the weight of the outputs, The weight of the inputs and \(E_p\) the efficiency of the unit \(i^{th}\). (Banker et al., 1984.)

The relationship between technical efficiency (TE), pure technical efficiency (PTE) (managerial efficiency), and scale efficiency (SE) is defined as Equation 3:

\[
\frac{TE}{PTE} = SE
\]

(3)

The scale efficiency will not be more than one. The efficiency of the CCR model is called total technical efficiency because it is not affected by scale and size. On the other hand, the BCC model shows pure technical efficiency under variable returns to scale. The above relationship shows the efficiency analysis, which shows the efficiency sources.
Which determines whether the inefficiency is due to managerial inefficiency or is due to conditions that indicate the scale efficiency or to both factors.

Data mining
A CART tree is a binary decision tree that is constructed by splitting a node into two child nodes repeatedly, beginning with the root node that contains the whole learning sample. Each node of a tree has two branches, which are related to the outcome of a test on one of the contextual variables. Data used in this study include 11 variables obtained from 20 sugarcane harvesting units during the years 2015-2020. The variables used were divided into two categories: predictive variables and target variables. The variables of pure technical efficiency and technical efficiency were considered as target variables (dependent variable) and other variables were considered as predictive variables (independent variable). In the CART model, the input data includes: harvesting area, the amount of crop harvested (ton), waste during harvest, fuel consumption, oil consumption, repair cost and replacement of parts in harvesters, harvest time, amount of trash sent to the factory (percentage), factory no-cane hours, technical efficiency and pure technical efficiency units of sugarcane harvesters. In this algorithm, 70% of the data were used for training and 30% of the data were used for testing. The Gini index was used to build the tree. Decision tree algorithm try to minimize diversity in the nodes. This non-uniformity in nodes can be measured using the impurity measure, the most important and most widely used method is the Gini index (Yoneyama et al., 2002). Figure 3 depicts the data modeling process using IBM SPSS Modeler 14.2.

![Data modeling process using IBM SPSS Modeler 14.2](image)

Results and Discussion
Determining efficient and inefficient sugarcane harvesting units
The results of a study of 20 sugarcane harvesting units in the CCR model showed that 6 units had an efficient score (30%) and 14 units (70%) had an inefficient score, and their technical efficiency score was in the range of 0.73-0.95 (Table 1). The results of the BCC model study also showed that out of a total of 20 sugarcane harvesting units, 8 units (40%) had efficient scores (Table 1). On the other hand, the remaining harvest units, which were 12 units (60%), scored less than 100 points and were inefficient. In the BCC model, more units are introduced as efficient units and there is less dispersion between inefficient units. Also, the distribution of efficient units in
the BCC model is less than the CCR model. The average values of pure technical efficiency, technical efficiency, and scale efficiency for all 20 units are 0.93, 0.88, and 0.93, respectively (Table 2). Ullah et al. (2019) analyzed the efficiency of different sugarcane production systems of Thailand. The result showed that the average efficiency score of sugarcane production systems is approximately 52%. The efficiency analysis indicates a huge potential for the improvement in efficiency through a reduction in the current pattern of farm inputs. The efficiency can also be improved by providing good management practices for sugarcane farms. Kaab et al. (2019) reported mean scores of technical efficiency, scale efficiency, and pure technical efficiency in sugarcane production in Iran as 0.91, 0.98, and 0.93, respectively. Khai and Yabe (2011) reported TE for paddy production in Vietnam as 0.816. Elhami et al. (2016) computed that TE, PTE, and SE for chickpea production in Isfahan province of Iran were 0.94, 0.99, and 0.94, respectively.

The average technical efficiency of inefficient units is 0.83, which shows that by using 83% of inputs and remaining the same output of them, these units can reach the efficiency limit and save 17% of inputs by increasing their efficiency (Table 1). The BCC analysis results in this table show that units 1, 5, 8, 11, 12, 13, 15, and 16 are efficient. The efficiency of the units means that each unit must be able to reduce its consumption of inputs by (1-0)% without reducing the amount of production. The efficiency of unit 2 is 0.81%. This means that unit 2 should be able to reduce its consumption from all inputs by 19% to reach the efficiency limit. In Table 1, the ranking results of the harvest units are based on the BBC and CCR input-oriented models, which rank the inefficient units, and all efficient units are prioritized in the rankings on the inefficient units and assigned the first rank. Ranking of efficient units will be based on the number of inefficient units to which reference is made. The ranking of inefficient units is based on the value of efficiency points they have earned. According to the CCR model, after six efficient units, unit No. 14 is ranked first among inefficient sugarcane harvesting units and 7th among all harvest units, followed by harvesting units number 18, 6, 12, 20, 17, etc., respectively. In the BCC model, after eight efficient units, the inefficient unit No. 14 ranks first among the inefficient harvesting units and 9th among the total units, and then the harvesting units number 18, 6, 17, 20, 19, etc., respectively, have the next ranks. If a unit is quite efficient in terms of the BBC model but has a low efficiency of the CCR model, then it is relatively efficient but not overall efficiency. So basically it is reasonable to determine the efficiency of the scale of a unit by these two functions. The technical efficiency of a unit with a constant return to scale (CRS) is obtained from the CCR model. However, in the case of variable efficiency compared to the variable scale (VRS) of the BCC model, technical efficiency can be calculated. The relationship between technical efficiency, pure technical efficiency (management), and scale efficiency is defined in Equation 3. The scale efficiency will not be more than one. The efficiency of the CCR model is called total technical efficiency, because it is not affected by scale and size. On the other hand, BCC shows pure technical efficiency under variable returns to scale. Relationship 3 shows the efficiency analysis that shows the relationship between the sources of inefficiency, i.e. it determines whether the inefficiency is due to managerial inefficiency or is due to the conditions that indicate the scale efficiency or from both factors. According to the results obtained in Table 1, units 12 and 13 operate locally efficiently (pure technical efficiency = 1) and total inefficiency (1 <total efficiency) is due to scale inefficiency. The inefficiencies of units 2, 3, 4, 6, 7, 9, 10, 14, 17, 17, 18, 19, and 20 are due to management inefficiency and also due to the condition of the units (scale inefficiency).

The structure of the CART tree was created to predict the technical efficiency and pure technical efficiency of sugarcane harvesting units is shown in Figures 3 and 4. In the
technical efficiency model, this tree consists of 4 nodes. Three of these nodes are the final nodes.

**CART algorithm**

The information and description of the input data in the CART model are given in Table 3.

**Table 1- Evaluation results of sugarcane harvesting units**

<table>
<thead>
<tr>
<th>DMU NO.</th>
<th>DMU Name</th>
<th>Technical efficiency score (CRS)</th>
<th>Ranking CCR</th>
<th>Pure technical efficiency score (VRS)</th>
<th>Ranking BCC</th>
<th>Scale efficiency score</th>
<th>RTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2015-2016...1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>Constant</td>
</tr>
<tr>
<td>2</td>
<td>2015-2016...2</td>
<td>0.81</td>
<td>15</td>
<td>0.86</td>
<td>17</td>
<td>0.94</td>
<td>Constant</td>
</tr>
<tr>
<td>3</td>
<td>2015-2016...3</td>
<td>0.73</td>
<td>18</td>
<td>0.88</td>
<td>16</td>
<td>0.82</td>
<td>Constant</td>
</tr>
<tr>
<td>4</td>
<td>2015-2016...4</td>
<td>0.89</td>
<td>13</td>
<td>0.91</td>
<td>15</td>
<td>0.97</td>
<td>Constant</td>
</tr>
<tr>
<td>5</td>
<td>2016-2017...1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>Constant</td>
</tr>
<tr>
<td>6</td>
<td>2016-2017...2</td>
<td>0.93</td>
<td>9</td>
<td>0.96</td>
<td>11</td>
<td>0.96</td>
<td>Increasing</td>
</tr>
<tr>
<td>7</td>
<td>2016-2017...3</td>
<td>0.75</td>
<td>16</td>
<td>0.78</td>
<td>20</td>
<td>0.96</td>
<td>Constant</td>
</tr>
<tr>
<td>8</td>
<td>2016-2017...4</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>Constant</td>
</tr>
<tr>
<td>9</td>
<td>2017-2018...1</td>
<td>0.70</td>
<td>19</td>
<td>0.86</td>
<td>18</td>
<td>0.81</td>
<td>Constant</td>
</tr>
<tr>
<td>10</td>
<td>2017-2018...2</td>
<td>0.68</td>
<td>20</td>
<td>0.79</td>
<td>19</td>
<td>0.86</td>
<td>Constant</td>
</tr>
<tr>
<td>11</td>
<td>2017-2018...3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>Constant</td>
</tr>
<tr>
<td>12</td>
<td>2017-2018...4</td>
<td>0.91</td>
<td>10</td>
<td>1</td>
<td>1</td>
<td>0.91</td>
<td>Constant</td>
</tr>
<tr>
<td>13</td>
<td>2018-2019...1</td>
<td>0.74</td>
<td>17</td>
<td>1</td>
<td>1</td>
<td>0.74</td>
<td>Constant</td>
</tr>
<tr>
<td>14</td>
<td>2018-2019...2</td>
<td>0.95</td>
<td>7</td>
<td>0.97</td>
<td>9</td>
<td>0.97</td>
<td>Decreasing</td>
</tr>
<tr>
<td>15</td>
<td>2018-2019...3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>Constant</td>
</tr>
<tr>
<td>16</td>
<td>2018-2019...4</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>Constant</td>
</tr>
<tr>
<td>17</td>
<td>2019-2020...1</td>
<td>0.90</td>
<td>12</td>
<td>0.95</td>
<td>12</td>
<td>0.94</td>
<td>Decreasing</td>
</tr>
<tr>
<td>18</td>
<td>2019-2020...2</td>
<td>0.94</td>
<td>8</td>
<td>0.96</td>
<td>10</td>
<td>0.97</td>
<td>Decreasing</td>
</tr>
<tr>
<td>19</td>
<td>2019-2020...3</td>
<td>0.88</td>
<td>14</td>
<td>0.92</td>
<td>14</td>
<td>0.95</td>
<td>Decreasing</td>
</tr>
<tr>
<td>20</td>
<td>2019-2020...4</td>
<td>0.91</td>
<td>11</td>
<td>0.92</td>
<td>13</td>
<td>0.98</td>
<td>Decreasing</td>
</tr>
</tbody>
</table>

Source: Own calculation

**Table 2- Efficiency average of harvesting units**

<table>
<thead>
<tr>
<th>Efficiency</th>
<th>Average</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure technical efficiency (efficiency in BCC model)</td>
<td>0.93</td>
<td>0.07</td>
</tr>
<tr>
<td>Technical efficiency (efficiency in CCR model)</td>
<td>0.88</td>
<td>0.11</td>
</tr>
<tr>
<td>Scale efficiency</td>
<td>0.93</td>
<td>0.07</td>
</tr>
</tbody>
</table>
Table 3- Description of variables used for this study

<table>
<thead>
<tr>
<th>Variable name</th>
<th>Unit</th>
<th>Average</th>
<th>Minimum amount</th>
<th>Maximum amount</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harvesting area</td>
<td>ha</td>
<td>2311</td>
<td>2017</td>
<td>2679</td>
<td>166.71</td>
</tr>
<tr>
<td>The amount of crop harvested</td>
<td>ton</td>
<td>179321</td>
<td>140942</td>
<td>215033</td>
<td>28501.01</td>
</tr>
<tr>
<td>Waste during harvest</td>
<td>kg</td>
<td>11856.5</td>
<td>8341</td>
<td>15032</td>
<td>1755.52</td>
</tr>
<tr>
<td>Fuel consumption</td>
<td>lit</td>
<td>364150</td>
<td>301000</td>
<td>448000</td>
<td>39205.63</td>
</tr>
<tr>
<td>Oil consumption</td>
<td>lit</td>
<td>10965.90</td>
<td>8600</td>
<td>13984</td>
<td>2003.51</td>
</tr>
<tr>
<td>Repair cost and replacement of parts in harvesters</td>
<td>Rials</td>
<td>766850000005800000000</td>
<td>12530000000</td>
<td>1763173798.02</td>
<td></td>
</tr>
<tr>
<td>Harvest time</td>
<td>day</td>
<td>113.60</td>
<td>98</td>
<td>140</td>
<td>14.37</td>
</tr>
<tr>
<td>The amount of trash sent to the factory (percentage)</td>
<td>ton</td>
<td>6.24</td>
<td>5.51</td>
<td>6.80</td>
<td>0.42</td>
</tr>
<tr>
<td>Factory no-cane hours</td>
<td>hr</td>
<td>23.95</td>
<td>0</td>
<td>59</td>
<td>17.17</td>
</tr>
</tbody>
</table>

Source: Own calculation

The first variable selected to create a branch in the tree is the amount of fuel consumed with the Gini index, 0.002. The next division is using the cost of repairs and replacement of parts in harvesters, which is divided into two branches, costs more than 1,200,000,000 Rials and less than 1,200,000,000 Rials. Also, in the pure technical efficiency model, the tree consists of 2 nodes. The variable selected to create a branch in the tree is the amount of fuel consumed with the Gini index, 0.001. The tree is divided into two branches, the amount of fuel consumed is more than 348,000 liters and less than 348,000 liters.

Efficiency-CRS

Fig.3. CART model predicting technical efficiency of sugarcane harvesting units
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Fig. 4. CART model predicting pure technical efficiency of sugarcane harvesting units

Modeling accuracy
Using the linear correlation relationship between the results predicted by the model and the actual results, it can be seen to what extent the resulting model has been successful in predicting the technical efficiency and pure technical efficiency of sugarcane harvesting units. According to Table 4, the accuracy of the CART model for predicting technical efficiency and pure technical efficiency was 86% and 93%, respectively.

Table 4 - Results for CART algorithm

<table>
<thead>
<tr>
<th>Variable</th>
<th>Technical efficiency</th>
<th>Pure technical efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Error</td>
<td>-0.036</td>
<td>-0.031</td>
</tr>
<tr>
<td>Maximum Error</td>
<td>0.077</td>
<td>0.017</td>
</tr>
<tr>
<td>Mean Error</td>
<td>0.008</td>
<td>-0.003</td>
</tr>
<tr>
<td>Mean Absolute Error</td>
<td>0.013</td>
<td>0.005</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>0.027</td>
<td>0.01</td>
</tr>
<tr>
<td>Linear correlation</td>
<td>0.86</td>
<td>0.93</td>
</tr>
</tbody>
</table>

Conclusion
In this study, using the DEA method, technical efficiency, pure technical efficiency, and scale efficiency in sugarcane harvesting units in Khuzestan province, in Iran were investigated. The results of CCR and BCC input-oriented models showed that the average technical efficiency, pure technical efficiency, and scale efficiency in the sugarcane harvesting units were 93%, 88%, and 93%, respectively. Since both CCR and BCC models used for calculating the technical and pure technical efficiencies are unit invariant, the extended models are recommended for future study. In the next step, using the CART decision tree method, the efficiency of sugarcane harvesting units was predicted. In the CART model, the input data includes 11 variables. The results showed that the fuel consumption variable in the CART model for predicting technical efficiency and pure technical efficiency has emerged as the most important independent variable in modeling. This study results showed that the accuracy of the CART model for the variables of technical efficiency and pure technical efficiency were 86% and 93%, respectively. Therefore, it can be clearly seen that the decision tree model has
a very good accuracy in estimating the values of technical efficiency and pure technical efficiency of sugarcane harvesting units. Finally, the results of this study show that the use of predictive methods, by providing an accurate picture of the situation of sugarcane harvesting in Amirkabir agro-industry, allows increasing the productivity of inputs.

References
کنترل توزیع واحدهای برداشت نیشکر با استفاده از یک روش و روش ترکیبی از تحلیل پوششی داده‌ها و داده‌کاوی

نیما منجزی

تاریخ دریافت: ۱۳۹۷/۱۲/۴۰
تاریخ پذیرش: ۱۳۹۸/۱۰/۲۷

چکیده

هر سازمانی به منظور آگاهی از میزان عملکرد و مطلوبیت فعالیت واحدهای خود به یک نظام ارزشیابی جهت سنجش این مطلوبیت نیاز دارد و این موضوع برای موسسات کشاورزی از جمله کشت و صنعت‌های دیگر اهمیت بیشتری دارد. در تحقیق حاضر، ۱۱ واحدهای برداشت نیشکر انتخاب گردید. پس از ساختاری بر مبنای مدل‌های CCR و BCC ورودی محور، مقایسه کارایی برای واحدهای برداشت نیشکر محاسبه گردید و با استفاده از درخت تصمیم CART به استخراج قوانین برای پیش‌بینی کارایی این واحدها پرداخته شد.

نتایج مطالعه ۱۱ واحدهای برداشت نیشکر در مدل CCR نشان داد که ۶ واحدها دارای امتیاز کارآمد و ۲۰ واحدها دارای امتیاز ناکارآمد بودند و امتیاز کارا بین آن‌ها در محدوده ۳۳/۴ تا ۱۹/۴ بود. نتایج مطالعه مدل BCC همچنین نشان داد که ۸ واحدها دارای امتیاز کارآمد بودند و امتیاز کارا بین آن‌ها در محدوده ۳۹/۴ تا ۳۶/۴ بود. در مدل BCC کمتر از مدل CCR است. میانگین کارایی فنی ۱۳/۸۸ درصد، کارایی فنی خالص ۱۳/۸۸ درصد و کارایی مقیاس بهترین برای ۳۸/۴۲ درصد به دست آمد. در مدل BCC همچنین دقت دقت درخت تصمیم تولید شده برای یک واحدهای نیشکر CART، تحلیل پوششی داده‌ها نیشکر

واژه‌های کلیدی: برداشت، تحلیل پوششی داده‌ها، نیشکر

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Evaluation of the Plateau Honing on the Friction and Wear Cylinder Liners in Agricultural Tractors

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2- MSc Student, Department of Biosystems Engineering, Ferdowsi University of Mashhad, Mashhad, Iran

Abstract

To enhance the fuel efficiency of the engines of agricultural tractors, the optimal control of interacting surfaces for improving engine performance becomes extremely significant, especially in developing the surface of cylinder liners. Therefore, plateau honing technology was designed on the cylinder liner of automotive and tractor engines. A substantially flat or plateau is left on the sliding surfaces along with more bearing areas, although a cross hatch model of valleys is kept for retaining oil. On the contrary, the created valley by honing functions as an oil repository can negatively affect creating fluid dynamic pressure on the surfaces. Accordingly, a better understanding of generated surfaces during plateau honing is essential for optimizing process. To this end, some experiments were performed on a cylinder liner of the Perkins 4-248 engine (related to the Massey Ferguson 285 tractor) which was manufactured by Keyhan Sanat Ghaem Company. Then, friction and wear tests with reciprocating motions were conducted to compare the lubricity of sliding cylinder liner surfaces with each different mark of plateau honing. Then, a comparison was made between the friction and wear of the surfaces including various depth of profiles, which were used as the honing mark of the agricultural tractors diesel engine, and those which had randomly ground surfaces. Based on this study results, higher amounts of wear volumes were produced by creating more interactions from asperity contacts and relatively thin films, compared to the test with the shallow-grooved honing marks.

Keywords: Cylinder liner, Friction, Plateau honing, Tractor engine, Wear

Introduction

Nowadays, the process of mechanization development highlights that an increase in the application of tractors in agriculture and the share of mechanical power in operations improves production (Khodabakhshian, 2013; Keshvari and Marzban, 2019). However, improved engine performance and reduced fuel and oil consumptions are among the requirements which challenge the agricultural tractor industry. In agricultural tractors, nearly 11.5% of the energy is utilized for the actual power while the remaining energy is lost. In addition, 18% of the energy loss occurs in mechanical parts, and the energy waste is related to friction losses. Fuel and oil consumption may be reduced by 2% when a 10% reduction occurs in friction losses. According to Khodabakhshian and Shakeri (2011), piston assembly and interface between piston rings and cylinder liners are considered as the most losses in the tractor engine.

Recently, controlling interacting surfaces optimally for increasing the engine performance has been highlighted, especially in designing the surface of cylinder liners to enhance the fuel efficiency related to the agricultural tractor engine. Recent approaches in improving high-speed engines necessitate having an engine with lighter weight, higher
performance, lower exhaust gasifiers, as well as less fuel consumption compared to previous ones (Grabon et al., 2018). Further such engines should have the ability for severe loading, which necessitates a reduction in the amount of wear. The process of making some grooves on the surface for lubricating purposes and controlling contact surfaces are considered as one of such methods in this regard. Thus, plateau honing technology was designed on the cylinder liner related to the tractor and automotive engines (Tomanik et al., 2018). A plateau honing results in producing flat or plateau finishes on sliding surfaces with a more bearing area while maintaining a cross hatch model of valleys for retaining oil (Kim et al., 2018a; Sadizade et al., 2020).

Texturing surface is considered as one of the most useful technologies for handling the friction between cylinder liners and piston rings. Some studies focused on a multi-stage honing operation and texturing laser surface on cylinder liners for reducing the friction (e.g., Kligerman et al., 2005; Anderberg et al. 2018). Ramadan et al. (2009) indicated that the honing process enhances the geometric shape of the cylinder liner in terms of its geometric properties, including ovality and roundness. The ovality of the cylinder increases frictions in the engine and the wear between the ring and the cylinder liner wall since it establishes an asymmetric contact surface between rings and pistons with the cylinder liner wall. This phenomenon leads to an increase in fuel consumption while it decreases the output power of the engine and thus the service life of engine parts through time, with additional wear between the ring and piston with the cylinder wall (Kim et al., 2018b). Accordingly, tractor manufacturing companies now employ more rigid standards with tight tolerances in the permitted level of cylinder liner roughness although these standards differ relying on the type of the engine and the diameter of the cylinder and piston.

To the best of our knowledge, no study has evaluated the influence of honing or plateau honing on friction and wear of tribological cylinder liner surfaces in agricultural tractors, as well as the effect of honing parameters on the functional parameters of the engine. Most studies in this area predicted the maintenance and repair costs of agricultural tractors and estimated the economic life of tractors (e.g., Almasi and Yeganeh, 2000; Khodabakhshian and Shakeri, 2011; Rohani et al., 2011). Furthermore, some studies investigated the application of the preventive net in maintenance and repair programs of agricultural machines (e.g., Khodabakhshian and Shakeri, 2011; Khodabakhshian, 2013). Contrarily, various studies evaluated honing and plateau honing technology on the cylinder liner of automotive and ship engines. For example, Buj-Corral et al. (2015) designed several models for optimizing the honing equipment of the driving liner by comparing the obtained data from the surface roughness test device in the laboratory and the existing Honing machine. Additionally, Cabanettes et al. (2015) obtained data regarding the surface roughness of the cylinder liner and its related wear. In addition, Yousfi et al. (2015) studied the effect of plateau honing parameters on the surface roughness of the driving cylinder liner. In another study, Kim et al. (2018b) examined the effect of the parameters related to plateau honing on creating friction and wear for the driving cylinder liner.

Considering the above-mentioned explanations, the present study attempted to assess the impact of plateau honing on creating the tribological cylinder liner surfaces for friction and wear in agricultural tractors. A change occurred in profile depth from 0.05 μm to 0.8 μm in \(R_a\), which often uses the honing mark related to the agricultural tractor engine. Further, a comparison was made between these surfaces and the randomly ground surface with a surface roughness of 0.15 and 0.25 μm in \(R_a\). To this end, a cylinder liner of the Perkins 4-248 engine (related to the Massey Ferguson 285 tractor and manufactured by Keyhan Sanat Ghaem Company) was applied to perform the test.

Materials and Methods

The spatial and temporal domain of the study
Keyhan Sanat Ghaem Company, as one of the largest manufacturers of cylinder liners in Iran and the Middle East, was selected as the case study. The current study was conducted in 2017 in this company. Given the aim of the present study regarding evaluating the cylinder liner of the agricultural tractor, the cylinder liner of the Perkins 4-248 engine was selected, which was associated with the Massey Ferguson 285 tractor. Fig. 1 depicts a sample of this cylinder liner.

**Tribological tests**

A reciprocating ring-liner tribometer driven by a slider-crank mechanism with a stroke length of 80 mm (Fig. 4) was implemented for evaluating the friction and wear characteristics of cylinder liner surfaces with different honing marks against piston ring surfaces with 27±2 °C temperature. Then, the contact surface was lubricated by using a 10W40 semi-synthetic oil (μD equal to 0.08 Pas at 40 °C). It should be noted that the total wear test took 120 min in which extra amounts of lubricant were summed (2-3 mL) every 20 min. In addition, the normal force and engine velocity used for these tests were 100 N and 120 rpm, respectively (Yousfi et al., 2015; Kim et al., 2018b).

![Fig.1. A sample of the cylinder liner](image)

The measured cylinder liner material involves high-quality cast iron (GG 25) which has a 101 mm bore diameter and 233 length. The chemical compositions of the grey cast iron are shown in Table 1. The inner surface of cylinder liners has a hardness of 225-272 HB. The metallography (ASTM A247) results indicated that the liner consists of cast iron along with the pearlite matrix and an insignificant amount of the steadite (iron phosphide eutectic network). Further, the form of graphite is type I, graphite distribution is pattern A, E, and graphite size is 4.5.

<table>
<thead>
<tr>
<th>Table 1 - Cylinder liner material specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Element</strong></td>
</tr>
<tr>
<td>% By weight</td>
</tr>
</tbody>
</table>

*Note. Cr: Chrome; S: Sulfur; P: Phosphorus; Mn: Manganese; C: Carbon.*

**Sample preparation**

First, the honing process from cylinder liners in the Perkins 4-248 engine block honing station was used for producing specimens by utilizing a mono spindle vertical honing machine by a developed instrument (NAGEL no. 28-8470) (Fig. 2). Cylinder blocks are delivered to the honing station after pressing and boring liners in the machining
line. Then, liner specimens were prepared with varied honing depths, representing a surface roughness of 0.05, 0.15, 0.25, 0.5, and 0.8 μm in Ra (Fig. 3). In addition, five honing marks were produced to assess the impact of the honing mark on the wear and friction related to the contacting surfaces. The final surface of engine liners in plateau honing should become 0.8 μm in Ra (in other words Rₖ 3.712, Rₚₖ 0.895, and Rₖₚ 2.321 values should be seen on the final surface) on the surface processed by long-stroke honing. Additionally, two surfaces were created by random grinding without any honing marks, and the surface roughness of which were 0.15 and 0.25 μm in Ra. Next, all liner specimens were mounted on a reciprocating tester along with cleaning with acetone. Finally, scanning electron and optical microscopes were utilized to examine worn tracks on surfaces.

Friction tests undertake a load level of 100 N and reciprocating velocity of 120 rpm (Yousfi et al., 2015; Kim et al., 2018b). The contact pressure is high and can reach up to 50 MPa thanks to a small contact surface between the liner and ring surface (nearly 2-3 mm²). Then, the friction was measured after 0, 15, 30, 60, and 120 min. Finally, the friction coefficient was calculated by applying the ratio between the average normal force (F_N) over the mean tangential force (F_T) assessed by strain gauges. The Rtec Multi-Function Tribometer software was used. A balanced Wheatstone bridge has been constructed by mounting four strain gauges over F_T. Two strain gauges have been mounted over the outer surface (for F_N), while rests are placed at the inner surface.

Fig. 2. (a) Vertical honing machine with an expansible tool and (b) Schematic representation of a honing head and its motion
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Results and Discussion

Running-in friction dependence on surface

Fig. 5 illustrates the specimen friction coefficient made by utilizing different surface processes. As displayed, compared to the surfaces with a grinding process with similar surface roughness, honing processed surfaces involve the coefficients with lower friction. Based on the results, no difference was observed in the friction performance related to the surface roughness of 0.8 μm in Ra in comparison to those of smoother surfaces. However, the highest friction coefficient was reported for polishing processed surfaces which confirmed some numerical results in the mixed lubrication regime (Mezghani et al., 2013; Yousfi et al., 2014). However, these findings should be approved by firing engine experiments that consider real engine conditions. These findings corroborate with those of Yousfi et al. (2015), Kim et al. (2018b), Anderberg et al. (2018), and Grabon et al. (2018).

Wear evolution during running-in
The evaluation method related to the wear volume of the cylinder liner during the plateau honing process compares the surface bearing as a curve of the original and plateau honed surface (Kumar et al., 2000; Srivastava et al., 2007). Further, this method represents that original surface depth is not eliminated when there is a negligible amount of wear. Fig. 6 illustrates the wear volumes related to cylinder liners with different roughness of the surface. The least volume of wear is created by the surfaces with the honing marks of 0.1-0.2 μm in $R_a$.

**Fig.5.** The friction coefficient related to surface roughness: (a) $R_a$ 0.25 μm, (b) $R_a$ 0.15 μm, and (c) $R_a$ 0.8 and 0.05 μm
However, the highest wear volume was observed in the surface roughness of 0.8 μm in \( R_a \). Based on the results, the volumes of wear increased by enhancing the surface roughness from 0.2 μm since colliding jagged asperities resulted in increasing in polishing effects. Contrarily, a decrease in the surface roughness from 0.1 μm led to an increase in the volumes of the wear by considering the fact that an increase in the real contact area between steel ball and cylinder liner results in creating more severe wear by adhesion. Other studies such as Yousfi \textit{et al.} (2015) and Kim \textit{et al.} (2018b) reported a similar trend for the wear volumes related to cylinder liners with different surface roughness.

In addition, the randomly ground surface indicated identical or better wear resistance after comparing the wear volumes related to the two machined surfaces, in comparison to the honing processed surface. It is worth noting that the surface valleys interrupt the maintaining hydrodynamic pressure of the lubricant film which results in creating partially metal-to-metal contact and plastic deformations by interacting asperities.

As shown in Fig. 6, the wear volume of the cylinder liner Scanning electron microscope (SEM) observations

To evaluate the effect of the honing mark on the wear, the honed surfaces with different surface roughness were considered for comparison. As shown in Fig. 7, the rough surface with 0.8 μm in \( R_a \) is rather damaged due to its plowing action and deep valley. In addition, the polished surface indicated a deep wear depth and higher plowing, while the wear mark related to the surface roughness of 0.5 μm in \( R_a \) is less than those of other surfaces.

As shown in Fig. 8, the surface with \( R_a \) 0.8 μm, which involves deeper grooves and a less contact area, demonstrates severe plastic deformations due to the interaction existing in colliding asperities. Based on the results, the grooves smeared by sliding surface and plastic deformations became smooth. Kim \textit{et al.} (2012) evaluated the effect of reserving oils on grooves as well. The results of the current study further represented that surfaces with \( R_a \) 0.25 and 0.15 μm still indicate several groove patterns after the sliding test. Furthermore, adhesive wear was observed by the smoothest surface with polishing, which produced higher
volumes of wear (Fig. 6). Thus, there is an optimum range of surface roughness to reduce the wear amount of the plateau honing process ranged between 0.15 and 0.25 μm in $R_a$. 

![Microscopic images before and after the experiment](image)

Fig. 7. Microscopic images before and after the experiment

Fig. 9 depicts SEM images measured by ground surfaces without any honing process. The amounts of the wear were almost similar in comparison to similar surfaces with honing. Although the optimum groove depth of plateau honing is available for reducing the amounts of wear, the effect of the groove by using the plateau honing process which is considered as an oil reservoir is insufficient for reducing the wear compared to using only the grinding process.
Conclusion

In general, increasing the fuel efficiency of the agricultural tractor engine requires a better understanding of the generated surfaces during the honing of cylinder liners. Therefore, the present study evaluated the impact of plateau honing marks on the cylinder liner of the Perkins 4-248 engine (related to the Massey Ferguson 285 tractor). To this end, five types of honing marks (with the surface roughness of 0.05, 0.15, 0.25, 0.5, and 0.8 μm in $R_a$) and two randomly ground surfaces including 0.15 and 0.25 μm in $R_a$ for the surface roughness were used for testing friction and wear. The tests were performed under the load level of 100 N and reciprocating velocity of 120 rpm with a 10W40 semi-synthetic oil. The main findings of the present study are as follows.

1. Based on the results of deep-grooved honing marks, higher amounts of wear volumes were created after severe interactions due to asperity contacts and the formation of relatively thin films in comparison to the test related to shallow-grooved honing marks.

2. The least volume of wear occurred for the surface with the honing mark ranged 0.15 and 0.25 μm in $R_a$.

3. Similar amounts of wear were observed for the tests without honing with a similar $R_a$ of 0.25 μm in comparison to the wear test with the honed surface.

4. Lubricant films were not enough for decreasing the surface interaction resulting from deep grooves regarding surfaces with the honing mark, which resulted in disrupting fluid film formation.

Acknowledgment

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and cooperation of the Faculty of Agriculture of Ferdowsi University of Mashhad.

References

بررسی تأثیر هوئینگ پلاتو بر روی اصطکاک و سایش بوش سیلندر در تراکتورهای کشاورزی

پژوهشکده:
نوریه ماهینی‌های کشاورزی
https://jame.um.ac.ir/

مقاله پژوهشی
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چکیده
به منظور افزایش بازده سوخت موتورهای تراکتورهای کشاورزی، کنترل بهینه سطح پرده برهم کنش برای بهبود عملکرد موتور به ویژه در توسعه سطح بوش سیلندر سپارچ شگفت‌انگیز می‌باشد. از این رو، فن آوری هوئینگ پلاتو بر روی بوش سیلندر موتورهای خودرو و تراکتور طراحی شد. یک سطح صاف یا پلتو در واقع با گذشتن سطح لغزشی به مناطق با سطح پایین‌تر نشانه اگرچه یک مدل هاشور متقاطع از شیارهای سطح برای تغییر داده شود، باید از طریق عملیات هوئینگ به‌عنوان مخزن روانی در مدل گاز دیاگموسی سیال بر روی سطح تأثیر منفی باعث تولید شده در طول فرآیند هوئینگ پلاتو برای بهبود ایجاد ضروری است. پیدا می‌شود در حالت انتقال یک بوش سیلندر موتور پرکنیز 842/4 (مربوط به تراکتور مسی فرگوسن 822) تولیدی شرکت کیهان صنعت قائم انجام شد. سپس، آزمون‌های اصطکاک و سایش با حرکت رفت و برگشت برای مقایسه روانکاری سطح بوش سیلندر با تیمارهای مختلف هوئینگ پلاتو انجام گردید. در نتیجه، مقایسه‌ای بین اصطکاک و سایشگری سطح از جمله عملیات مختلف پروفایل‌ها که به‌عنوان تیمارهای مختلف هوئینگ موتور درایی استفاده شده و آن‌ها که دارای سطح تصادفی بوده انجام گردید. بر اساس نتایج، مقایسه با تیمارهای مختلف فعالیت‌های بیشتر از تماس‌های زبری و فیلم‌های نسبتاً نازک، در مقایسه با تیمارهای هوئینگ شیر کم عمق تولید شد.

واژه‌های کلیدی: اصطکاک، بوش سیلندر، سایش، موتور تراکتور، هوئینگ پلاتو

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Effect of Infrared Drying on Drying Kinetics and Color Changes of Wild Sage Seed Mucilage

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Abstract
In this study, the effects of infrared (IR) dryer system parameters such as IR power, the distance of mucilage from lamp surface, mucilage thickness on drying kinetics and, color indexes (L*, a*, b* and ΔE) of wild sage seed mucilage (WSSM) were investigated in an IR dryer system. Experimental moisture ratio (MR) data were fitted to 7 various empirical thin-layer models. It was found that the Page model has the best fit to show the kinetic behavior and acceptably described the IR drying behavior of WSSM with the lowest mean square error (MSE), root mean square error (RMSE), mean absolute error (MAE), and standard error (SE) values and the highest correlation coefficient (r) value. The values of MSE, RMSE, and MAE for all experiments were in the range of 0.1×10⁻³-1.1×10⁻³, 1.04×10⁻²-3.25×10⁻² and 8.7×10⁻³-27.1×10⁻³, respectively. The average effective moisture diffusivity (Déf) increased from 4.61×10⁻⁹ m² s⁻¹ to 15.8×10⁻⁹ m² s⁻¹ with increasing lamp power from 150 W to 375 W, while it was decreased from 14.4×10⁻⁹ m² s⁻¹ to 5.16×10⁻⁹ m² s⁻¹ and 13.2×10⁻⁹ m² s⁻¹ to 4.31×10⁻⁹ m² s⁻¹ with increasing the distance of mucilage from 4 to 12 cm and the reduction of mucilage thickness from 1.5 to 0.5 cm, respectively. Increasing in IR radiation power has a positive influence on the yellowness (increasing 19.78% in b* index) of dried WSSM. Also, it increased the color changes index (ΔE) from 16.05 to 17.59.

Keywords: Color indexes, Effective moisture diffusivity, Gum, Moisture ratio, Page model

Introduction
Fruits and vegetables drying is a commonly used process for improving product safety as it greatly decreases the microbial activity and enzymatic changes during the storage period, hence, increasing the shelf life of the product. One of the best ways to reduce the drying time is to provide heat by infrared (IR) radiation. IR methods could be used as a substitution to the current drying methods for producing high-quality dried hydrocolloids. IR heating has many advantages including high heat transfer rate, uniform heating, short processing time, high efficiency (80-90%), lower energy consumption, lower energy costs, and improving final product quality (Salehi, 2020a). In addition, the use of IR dryers in combination with other dryers helped to decrease the drying time by rising the drying rate that leads to reduced energy utilization. Also, symmetrical temperature sharing by IR improved final product quality (Baeghbali et al., 2019).

The dispersion of water-soluble hydrocolloids (gums) in the aqueous system provides great technical importance, since they can improve the gelling or thickening properties of food products (Zameni et al., 2015). The genus Salvia (Labiatae) contains more than 700 species of mucilaginous

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endemic plant. Wild sage (*Salvia macrosiphon* L.) is the mucilaginous native plant that is grown in different regions of Asia, Europe, and Middle East, especially in various regions of Iran and its seeds have a high content of mucilage (gums or hydrocolloids) with outstanding useful characteristics that is comparable with marketable food gums. Wild sage seeds are round small seeds, with a mucilage layer on their surface, which could swell in water, giving a viscous suspension. Wild sage seed mucilage (WSSM) is a gum extracted from the wild sage seed. Salehi and Kashaninejad (2015) reported that the apparent viscosity of WSSM solution (0.6% w/w), was varied from 0.162 to 0.344 Pa.s (60 s⁻¹), and freeze-dried WSSM exhibited the highest viscosity value among all dried gums. Also, the amounts of hardness, stickiness, consistency and adhesiveness of WSSM gel (3% w/w) were changed from 45.7 to 78.2 g, 9.8 to 17.0 g, 340.4 to 794.8 g.s, and 91.4 to 159.2 g.s at different drying conditions. In the bakery products gums have been used to improve dough performance, breads and cakes characteristics, textural and sensorial quality and extend the shelf life of the products (Salehi, 2019a). For example, the effect of the WSSM (at four levels of 0, 0.5, 1 and 1.5%, w/w) on physicochemical characteristics and sensorial properties of apple cake was studied by Salehi (2017). The authors reported that adding WSSM to apple cake batter reduced the density and improved its volume, lightness (*L* *⁰*), and sensorial parameters (appearance, crumb color lightness, porosity, flavor, texture, and overall acceptance).

The physicochemical properties and rheological behavior of dried seed gums depend on the method and condition of drying. Also, the color of the dried products is an important quality factor, which is affected by the drying conditions. For example, the effect of different drying methods (oven drying with temperature changes 40-80°C, freeze-drying and, vacuum oven-drying) on rheological behavior, color and physicochemical characteristics of basil seed mucilage was investigated by Salehi and Kashaninejad (2017). The color of oven-dried gum was darker (lower *L* *⁰* index values) in comparison to the freeze-dried or vacuum oven dried gums. In addition, the drying procedure can provide a broad range of molecular weight depending on the type and condition of drying. Nep and Conway (2011) reported that the grewia gum demonstrated the various degrees of viscosity varying from 0.2 to 0.32Pa.s depending on the drying method. However, there is no study available in the literature regarding the effect of IR drying techniques on the drying kinetics, *D* *eff* and color changes of WSSM. Therefore, this study aimed to investigate the effect of IR drying on the drying kinetics, *D* *eff* and color changes of WSSM.

**Materials and Methods**

**Gum extraction**

Wild sage seeds were purchased from a local market in Hamedan, Iran. They were physically cleaned and all foreign materials were removed. Then, the pure wild sage seeds were immersed in water for 20 min at a seed/water portion of 1:20 at 25°C. In the next step, the gum was separated from the inflated seeds by passing the seeds through an extractor (M-J-376-N, Nikko Electric Industry Company, Iran) with a rotating disc that scratched the mucilage layer on the seed surface. The initial moisture content (MC) of the WSSM was 99.4% (wet basis). The moisture content of WSSM was determined in an atmospheric oven at 105°C for 4 h (AOAC, method no. 934.06). Finally, the obtained WSSM was immediately placed into the IR dryer (Figure 1).

**IR drying**

The extracted WSSM was transferred in the cylindrical aluminum containers and then dried in an IR dryer (length 44 cm, width 20 cm, and height 40 cm). The effect of IR lamp (IR radiation lamp (NIR), Noor Lamp Company, Iran) power (at three levels 150, 250 and 375 W), the distance of sample from lamp (at three levels 4, 8, and 12 cm), mucilage thickness (at three levels 0.5, 1 and 1.5 cm) and time on the drying kinetics of WSSM was investigated (Amini *et al.*, 2021).
The weight changes of WSSM were measured using a LutronGM-300p digital balance (Taiwan, sensitivity of ±0.01 gr).

**Drying kinetics**

Numerical modeling is one of the appropriate methods for describing the drying kinetics of food products (Salehi, 2020b). For numerical modeling the drying kinetic behavior of WSSM, 7 commonly used thin-layer models including Quadratic, Page, Newton, Midilli, Logarithmic, Verma, and Two terms were examined (Akpinar and Bicer, 2005; Doymaz, 2011). In these models, dimensionless MR were defined as equation (1):

\[
MR = \frac{M_t - M_e}{M_0 - M_e}
\]  

(1)

Where \(M_t\) is MC of the sample (gr water/gr dry matter) at time \(t\); \(M_e\) and \(M_0\) are equilibrium and initial MC (gr water/gr dry matter), respectively. In equation (1), since \(M_e<<M_t\) and \(M_e<<M_0\), the value of \(M_e\) is negligible and the equation was simplified to \(M_t/M_0\) (Arunsandeep and Chandramohan, 2018; Ceylan et al., 2007; Doymaz, 2011).

Regression analysis was done using Curve Expert software (Version 1.34, Hyams, D. G., Microsoft Corporation) to evaluate equations parameters. Mean square error (MSE), root mean square error (RMSE), mean absolute error (MAE), and standard error (SE), and correlation coefficient \((r)\) values were calculated using equations 2 to 6 to evaluate the accuracy of models. It is noted that the highest \(r\)-value (closer to one) and the lowest MSE, RMSE, MAE, and SE values (closer to zero) represent the best model (good fitting).

\[
MSE = \frac{1}{N} \sum_{i=1}^{N} (O_i - T_i)^2
\]  

(2)

\[
RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (O_i - T_i)^2}
\]  

(3)

\[
MAE = \frac{1}{N} \sum_{i=1}^{N} |O_i - T_i|
\]  

(4)

\[
SE = \frac{\sigma}{\sqrt{N}}
\]  

(5)

\[
r = 1 - \frac{\sum_{i=1}^{N} (O_i - T_i)^2}{\sum_{i=1}^{N} (O_i - T_m)^2}
\]  

(6)

Where \(O_i\) is the \(i^{th}\) actual value, \(T_i\) is the \(i^{th}\) predicted value, \(T_m\) is the mean predicted value, \(N\) is the number of data, \(\sigma\) is the standard deviation, and \(T_m\) is given by:

\[
T_m = \frac{\sum_{i=1}^{N} O_i}{N}
\]  

(7)

**Calculation of Moisture Diffusivity \((D_{eff})\)**

Drying of food products occurs in two periods of constant and falling rates and drying of them is controlled by internal diffusion phenomenon. Fick’s second law of diffusion
can be used to describe the thin layer drying of these products at the falling rate (Sacilik, 2007). According to this law, MR for different geometries including cylinder, slab and sphere is defined as equation 8:

$$\frac{\partial MR}{\partial t} = D_{eff} \nabla^2 MR$$

(8)

Analytical solution of this equation for infinite slab geometry and with assuming a constant moisture distribution, one-dimensional moisture, negligible shrinkage, and negligible external resistance used to predict moisture diffusion in samples. The dimensionless MC values were calculated with the equilibrium moisture content determined by dynamic equilibrium data of samples. It is given as equation 9:

$$MR = \frac{8}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{(2n+1)^2} \exp\left(-\left(\frac{D_{eff} t}{4L^2}\right)^2\right)$$

(9)

Where t is the drying time (s), $D_{eff}$ is the effective moisture diffusivity (m$^2$/s); L is half-thickness of WSSM samples which are equal to 0.25×10$^{-2}$, 0.5×10$^{-2}$, and 0.75×10$^{-2}$ m in this study.

For long drying process period, Eq. (10) can be further simplified to:

$$MR = \frac{8}{\pi^2} \exp\left[-\frac{\pi^2 D_{eff} t}{4L^2}\right]$$

(10)

Hence, a logarithmic form was introduced as follows:

$$\ln MR = \ln\left(\frac{8}{\pi^2}\right) - \frac{\pi^2 D_{eff} t}{4L^2}$$

(11)

The $D_{eff}$ was calculated through Eq. (11) by using the method of slopes. From Eq. 12, a plot of experimental drying data in terms of lnMR versus time gives a straight line with a slope (K) of:

$$\text{Slope}(K) = -\frac{\pi^2 D_{eff}}{4L^2}$$

(12)

**Color measurement**

WSSM chromaticity was measured before and after drying in CIE lab system using the digital imaging method cited in the literature. CIE lab color parameters of L*, a* and b* represent darkness-lightness (0-100), color of greenness (-a*) to redness (+a*), and color of blueness (-b*) to yellowness (+b*), respectively (Salehi, 2019b). Therefore, the fresh and dried WSSM of each experiment were placed on the scanner surface and samples photos (RGB signals) were obtained (Hp Scanjet 300). Then, the taken photos from dried WSSM were loaded to a computer, and L*, a* and, b* indexes values were measured via ImageJ (1.42e, USA) software.

Another color parameter that was calculated is color changes index ($\Delta E$) which was calculated by total color difference as follow:

$$\Delta E = \sqrt{\left(\Delta L^*\right)^2 + \left(\Delta a^*\right)^2 + \left(\Delta b^*\right)^2}$$

(13)

Where $\Delta L$ is $L_2$-$L_1$, $\Delta a$ is $a_2$-$a_1$ and $\Delta b$ is $b_2$-$b_1$.

**Statistical analysis**

The experimental data were subjected to an analysis of variance (ANOVA) for a completely random design using a statistical analysis system (SAS 9.1, 2003, Institute, Inc.). Significant difference between data means was determined using Duncan’s multiple range test at P-value<0.05 and it was performed to establish the impact of IR radiation power (150, 250, and 375 W), the distance of the sample from lamp (4, 8 and, 12 cm), mucilage thickness (0.5, 1 and 1.5 cm) on drying time of WSSM (P-value<0.05). All measurements were conducted in triplicate.

**Results and Discussion**

**Drying time**

Statistical analysis of experimental results (data) demonstrated that the IR power, samples distance and mucilage thickness have a significant effect on the evolution of drying time of WSSM (p<0.01) (Table 1). In conclusion, experimental results showed that the infrared power, mucilage distance, mucilage thickness, infrared power × mucilage distance, infrared power × thickness, and mucilage distance × mucilage thickness, have significant effects on the drying time of WSSM. The interaction effects of IR lamp power, and mucilage distance, IR lamp power, and mucilage thickness, and mucilage distance and mucilage thickness on the drying time of WSSM are shown in Figure 2.
Table 1 - Results of analysis of variance for drying time parameters of wild sage seed mucilage drying

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<th>Degrees of freedom</th>
<th>Sum of squares</th>
<th>Mean square</th>
<th>P</th>
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</tr>
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<tr>
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<tr>
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<tr>
<td>Total</td>
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<td></td>
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</table>

Fig. 2. The interaction effects of IR lamp power and mucilage distance (a), IR lamp power and mucilage thickness (b), and mucilage distance and mucilage thickness (c) on the drying time of wild sage seed mucilage. Means with different superscripts differ significantly (P<0.05).

As expected, drying time was decreased by increasing the power because of increased temperature and heat transfer gradient between air and samples. The average drying times of WSSM were 172.04, 104.26, and 58.93 min at 150, 250 and 375 W, respectively. In addition, the drying time of WSSM was increased by increasing the distance of mucilage from the lamp surface and mucilage thickness. The average drying time reduced from 160.81 min to 72.03 min and from 173.67 min to 55.59 min when the mucilage distance and mucilage thickness were decreased from 12 to 4 cm, and from 1.5 to 0.5 cm, respectively.

The effects of IR power, samples distance and mucilage thickness on the MC of WSSM are shown in Figure 3. MC of WSSM was decreased with increasing the power because of the increasing temperature and heat transfer gradient between the air and samples. With
increasing IR intensity, due to the increase in mucilage temperature and increasing evaporation rate and the decrease in drying time, the specific energy for drying of WSSM decreases.

![Graphs showing variations of moisture content (MC) with drying time at different conditions: (a) IR power, (b) Sample distance, and (c) Sample thickness.](image)

**Fig. 3.** Variations of moisture content (MC) with drying time of wild sage seed mucilage at different: a) IR power (4 cm distance and 1.0 cm thickness); b) Sample distance (375W and 1.0 cm thickness); c) Sample thickness (375W and 8 cm distance).

**Fitting of the Drying Curves**

To estimate the drying kinetics of food products, numerous empirical models have been used by researchers. In this study, 7 thin-layer equations were selected and fitted to experimental data to choose the best and most suitable equation. The model with the highest $r^2$ value and the lowest MSE, RMSE, MAE, and SE values was selected as the best suitable model describing the IR drying processes of WSSM. The model that satisfied these features was the Page model (Eq. 14):

$$MR = \exp\left(-kt^n\right)$$ (14)
Where MR and t are moisture ratio and drying time, respectively. The estimated parameters (fitting data) of the Page model including drying constants, k, and n, are tabulated in Table 2 along with corresponding statistical data (MSE, RMSE, MAE, SE and r) for all experiments conditions. The values of MSE, RMSE and MAE for all experiments were in the ranges of 0.1×10^{-3}-1.1×10^{-3}, 1.04×10^{2}-3.25×10^{2} and 8.7×10^{3}-27.1×10^{3}, respectively. Also, the values of r and SE for all experiments were in the ranges of 0.995-0.999 and 0.010-0.031, respectively.

Figure 4 shows the comparison of fitted MR data by Page model with experimental results (375 W, 4 cm distance, and 1.0 cm thickness). These results indicate that Page model is appropriate in describing the drying characteristics of WSSM under the various IR drying conditions.

<table>
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<tr>
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<th>Thickness (cm)</th>
<th>k</th>
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<th>MSE</th>
<th>RMSE</th>
<th>MAE</th>
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**Fig.4.** Comparison of fitted data by Page model with experimental results (375 W, 4 cm distance and 1.0 cm thickness).
Fig. 5. Variations of the Ln (MR) with drying time of wild sage seed mucilage at different: a) IR power (4 cm distance and 1.0 cm thickness); b) Sample distance (375W and 1.0 cm thickness); c) Sample thickness (375W and 8 cm distance).
Moisture Diffusivity

The effect of IR drying systems on the $D_{\text{eff}}$ of some fruits and vegetables was studied by Salehi (2020a). The $D_{\text{eff}}$ values lie within a range of $10^{-8}$ to $10^{-10}$ m$^2$s$^{-1}$ for fruits and vegetables. The $D_{\text{eff}}$ values are determined by plotting experimental drying data in terms of $\lnMR$ versus time. The effects of IR radiation power, samples distance, and mucilage thickness on the $\lnMR$ are shown in Figure 5. The results of such fitting gave an average $D_{\text{eff}}$ of wild sage seed mucilage at different IR drying conditions. The values of $D_{\text{eff}}$ at different conditions drying of WSSM obtained by using Eq. (19) and estimated values are shown in Table 3.

The $D_{\text{eff}}$ values of WSSM were ranged from $1.31 \times 10^{-9}$ to $4.15 \times 10^{-9}$ m$^2$s$^{-1}$. $D_{\text{eff}}$ values increased with increasing IR radiation power because of the rapid movement of water at high temperatures (Doymaz, 2011).

The average $D_{\text{eff}}$ values increased with increasing mucilage thickness and they were equal to $4.31 \times 10^{-9}$, $10.5 \times 10^{-9}$ and $13.2 \times 10^{-9}$ m$^2$s$^{-1}$ for 0.5, 1.0 and 1.5 cm thickness of mucilage, respectively. In addition, the average $D_{\text{eff}}$ values decreased from $14.4 \times 10^{-9}$ to $5.16 \times 10^{-9}$ m$^2$s$^{-1}$ with increasing distance of mucilage from 4 to 12 cm.

The values of $D_{\text{eff}}$ are comparable with the reported values of $1.00 \times 10^{-8}$ to $3.72 \times 10^{-8}$ m$^2$s$^{-1}$ for dried quince in the IR system (Mehmnia et al., 2017) and $0.87 \times 10^{-9}$ to $2.64 \times 10^{-9}$ m$^2$s$^{-1}$ for dried pomegranate arils in the IR system (Briki et al., 2019). These values are consistent with the present estimated $D_{\text{eff}}$ values for WSSM. The results of such fitting gave an average regression coefficient of 0.91 indicating that the quality of such fitting was satisfactory.

### Color measurement

The quality attributes of WSSM during IR drying at various conditions as measured by the changes in color parameters of $L^*$, $a^*$, $b^*$ and, $\Delta E$ are shown in Table 4. The fresh WSSM exhibited a light color, with $L_1^*$, $a_1^*$...
and,  \(b^*\) equal to 87.69, -0.11 and, -0.90, respectively. The IR radiation power was found to have a significant effect on the color of WSSM. The rise in power has a negative effect on the \(\Delta E\) and with increasing in IR radiation power from 150 to 375 W, it was increased from 16.05 to 17.59. As shown in Table 4, the \(L^*\) values varied from 85.82 to 87.01 at various drying conditions. The rise in power has a positive effect on the \(b^*\) index and with increasing in IR power from 150 to 375 W, it was increased from 13.65 to 16.35. Onwude et al. (2018) reported similar changes in the color values of sweet potatoes undergoing IR drying.

### Table 4- Color parameters results of IR dried wild sage seed mucilage.

<table>
<thead>
<tr>
<th>Power (W)</th>
<th>Distance (cm)</th>
<th>Thickness (cm)</th>
<th>(L^*)</th>
<th>(a)</th>
<th>(b)</th>
<th>(\Delta E)</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>4</td>
<td>0.5</td>
<td>96.67±0.69</td>
<td>-1.28±0.14</td>
<td>7.33±0.66</td>
<td>12.24</td>
</tr>
<tr>
<td>150</td>
<td>4</td>
<td>1.0</td>
<td>83.13±0.86</td>
<td>1.38±0.16</td>
<td>19.63±0.91</td>
<td>21.08</td>
</tr>
<tr>
<td>150</td>
<td>4</td>
<td>1.5</td>
<td>80.25±0.75</td>
<td>1.68±0.08</td>
<td>18.70±0.27</td>
<td>21.04</td>
</tr>
<tr>
<td>150</td>
<td>8</td>
<td>0.5</td>
<td>94.98±0.31</td>
<td>-0.47±0.06</td>
<td>4.71±0.52</td>
<td>9.20</td>
</tr>
<tr>
<td>150</td>
<td>8</td>
<td>1.0</td>
<td>85.67±0.33</td>
<td>1.24±0.10</td>
<td>12.98±0.33</td>
<td>14.09</td>
</tr>
<tr>
<td>150</td>
<td>8</td>
<td>1.5</td>
<td>80.63±0.26</td>
<td>1.78±0.10</td>
<td>16.90±0.19</td>
<td>19.24</td>
</tr>
<tr>
<td>150</td>
<td>12</td>
<td>0.5</td>
<td>92.98±0.79</td>
<td>-0.34±0.13</td>
<td>9.75±0.13</td>
<td>11.89</td>
</tr>
<tr>
<td>150</td>
<td>12</td>
<td>1.0</td>
<td>87.88±0.22</td>
<td>0.14±0.06</td>
<td>9.81±0.64</td>
<td>10.72</td>
</tr>
<tr>
<td>150</td>
<td>12</td>
<td>1.5</td>
<td>80.93±0.14</td>
<td>1.58±0.16</td>
<td>23.03±0.59</td>
<td>24.92</td>
</tr>
<tr>
<td>250</td>
<td>4</td>
<td>0.5</td>
<td>89.82±1.34</td>
<td>-0.60±0.16</td>
<td>15.69±2.11</td>
<td>16.73</td>
</tr>
<tr>
<td>250</td>
<td>4</td>
<td>1.0</td>
<td>85.92±0.89</td>
<td>0.61±0.13</td>
<td>18.63±1.38</td>
<td>19.62</td>
</tr>
<tr>
<td>250</td>
<td>4</td>
<td>1.5</td>
<td>81.25±0.37</td>
<td>1.29±0.11</td>
<td>23.68±0.25</td>
<td>25.45</td>
</tr>
<tr>
<td>250</td>
<td>8</td>
<td>0.5</td>
<td>95.88±0.28</td>
<td>-0.70±0.06</td>
<td>6.00±0.69</td>
<td>10.72</td>
</tr>
<tr>
<td>250</td>
<td>8</td>
<td>1.0</td>
<td>86.02±0.70</td>
<td>0.41±0.08</td>
<td>15.70±0.44</td>
<td>16.69</td>
</tr>
<tr>
<td>250</td>
<td>8</td>
<td>1.5</td>
<td>82.20±0.30</td>
<td>1.69±0.04</td>
<td>18.84±0.35</td>
<td>20.57</td>
</tr>
<tr>
<td>250</td>
<td>12</td>
<td>0.5</td>
<td>94.47±0.19</td>
<td>-0.49±0.06</td>
<td>9.16±0.72</td>
<td>12.14</td>
</tr>
<tr>
<td>250</td>
<td>12</td>
<td>1.0</td>
<td>85.57±0.17</td>
<td>1.24±0.07</td>
<td>14.86±0.03</td>
<td>15.96</td>
</tr>
<tr>
<td>250</td>
<td>12</td>
<td>1.5</td>
<td>82.53±0.35</td>
<td>1.88±0.03</td>
<td>17.55±0.49</td>
<td>19.26</td>
</tr>
<tr>
<td>375</td>
<td>4</td>
<td>0.5</td>
<td>80.45±1.36</td>
<td>3.37±0.39</td>
<td>21.04±0.89</td>
<td>23.36</td>
</tr>
<tr>
<td>375</td>
<td>4</td>
<td>1.0</td>
<td>83.87±0.54</td>
<td>1.37±0.14</td>
<td>23.30±0.52</td>
<td>24.54</td>
</tr>
<tr>
<td>375</td>
<td>4</td>
<td>1.5</td>
<td>87.26±0.89</td>
<td>0.76±0.25</td>
<td>24.95±0.97</td>
<td>25.86</td>
</tr>
<tr>
<td>375</td>
<td>8</td>
<td>0.5</td>
<td>86.26±1.52</td>
<td>-0.12±0.12</td>
<td>10.47±0.21</td>
<td>11.46</td>
</tr>
<tr>
<td>375</td>
<td>8</td>
<td>1.0</td>
<td>86.77±1.97</td>
<td>-0.19±0.25</td>
<td>13.12±0.32</td>
<td>14.05</td>
</tr>
<tr>
<td>375</td>
<td>8</td>
<td>1.5</td>
<td>88.81±1.44</td>
<td>0.34±0.15</td>
<td>11.69±0.55</td>
<td>12.65</td>
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<tr>
<td>375</td>
<td>12</td>
<td>0.5</td>
<td>90.21±0.44</td>
<td>-0.21±0.09</td>
<td>7.21±0.39</td>
<td>8.50</td>
</tr>
<tr>
<td>375</td>
<td>12</td>
<td>1.0</td>
<td>84.89±0.85</td>
<td>0.41±0.05</td>
<td>18.34±0.22</td>
<td>19.45</td>
</tr>
<tr>
<td>375</td>
<td>12</td>
<td>1.5</td>
<td>83.85±1.00</td>
<td>2.07±0.18</td>
<td>16.99±0.41</td>
<td>18.42</td>
</tr>
</tbody>
</table>

\(L^*\) (darkness/lightness, 0 to 100), \(a\) (greenness/redness, -120 to 120) and \(b\) (blueness/yellowness, -120 to 120).

### Conclusion

The IR lamp power, the distance of mucilage from lamp and, mucilage thickness influenced the drying time of WSSM. The average drying time of WSSM samples was 172.04, 104.26 and 58.93 min at 150, 250 and, 375 W, respectively. The drying characteristics were satisfactorily described by the Page model with the highest \(r\) value (greater than 0.99) and the lowest MSE, RMSE, MAE and SE values (a good fit). Values for the \(D_{\text{eff}}\) of WSSM samples were obtained in the range of \(1.31\times10^{-9}\) and, \(4.15\times10^{-9}\) m² s⁻¹ and, they were increased with increasing lamp power while decreased with increasing distance of mucilage from lamp and mucilage thickness. Color parameters were estimated in terms of \(L^*, a^*\) and, \(b^*\) indexes and total color difference \(\Delta E\) measurements. The increases in IR radiation power have a negative influence on \(\Delta E\) and with rising in IR power from 150 to 375 W, it was increased from 16.05 to 17.59.

### List of symbols

- \(\Delta E\): Color changes index
- \(D_0\): Pre-exponential factor (m² s⁻¹)
- \(D_{\text{eff}}\): Effective moisture diffusivity (m² s⁻¹)
- \(k\): Drying rate constants in models (s⁻¹)
- K: Slope
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L  Half slab thickness of the samples (m)  MR  Moisture ratio
M₀  Initial MC (kg water/kg dry matter)  n  Number of constants
Me  Equilibrium MC (kg water/kg dry matter)  N  Number of observations
Mₜ  MC at time t (kg water/kg dry matter)  r  Correlation coefficient

t  Drying time (min)

References
تأثیر خشک کردن فروسرخ بر سینتیک خشک شدن و تغییرات رنگ موسیلاژ دانه مرو

غزاله امینی 1، فخرالدین صالحی 2، مجید رسولی 3*

چکیده

در این مطالعه، تأثیر پارامترهای سیستم خشک کردن فروسرخ شامل قدرت فروسرخ، فاصله موسیلاژ از سطح لامپ، ضخامت موسیلاژ بر روی سینتیک خشک شدن و شاخصهای رنگ (L*, a*, b* و ΔE) موسیلاژ دانه مرو را با کمترین مقدار ضایعات خطای ریجکسی (MSE)، جذر میانگین مربعات خطای (RMSE)، میانگین خطای نقطه (MAE) و خطا استاندارد (SE) مطالعه کرد. مدل نمایسشگی (Page) بیشترین تناسب رفتار سینتیک را نشان داد و به‌طور قابل قبولی رفتار خشک کردن فروسرخ موسیلاژ دانه مرو را با کمترین مقدار خطای میانگین مربعات (MSE)، جذر میانگین مربعات خطای (RMSE)، میانگین خطای نقطه (MAE) و خطا استاندارد (SE) توصیف کرد.

متوسط نفوذ مؤثر رطوبت (D_eff) با افزایش قدرت لامپ از 709 به 310 وات از 0.79 × 0.17 به 0.79 × 0.70 مترمربع بر ثانیه افزایش یافت، اما با افزایش فاصله موسیلاژ از 0 به 71 سانتی‌متر و کاهش ضخامت موسیلاژ از 0/9 به 0/9 سانتی‌متر، این ضریب به ترتیب از 0.79 × 0.70 به 0.79 × 310/0 مترمربع بر ثانیه کاهش یافت. افزایش قدرت تابش فروسرخ تأثیر مثبتی بر شاخص زردی (افزایش 10/70 درصدی در شاخص b* موسیلاژ دانه مرو خشک شده داشت.

واژه‌های کلیدی: شاخصهای رنگی، صعیف، دمای پیچ، نسبت رطوبت، نفس مؤثر رطوبت

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Diagnosis of Early Blight Disease in Tomato Plant based on Visible/Near-Infrared Spectroscopy and Principal Components Analysis- Artificial Neural Network Prior to Visual Disease Symptoms

F. Azadshahraki1*, K. Sharifi2, B. Jamshidio3, R. Karimzadeh4, H. Naderi5

Abstract

Early diagnosis of plant diseases before the occurrence of symptoms can reduce the loss of the yield and increase the quality of agricultural crops. It also reduces the consumption of pesticides, environmental risks, and the cost of production. For this reason, the objectives of the present study were non-destructive diagnosis of early blight of tomato plant and discrimination of the most important agents of early blight (A. solani and A. alternate) in the primary stages of incidence of the disease before appearing visual symptoms using Vis-NIR spectroscopy (400-900 nm). The spectral data were acquired from the leaves of the plants infected with A. solani and A. alternate, 48 hours, 72 hours, 96 hours, and 120 hours after inoculation. To develop the recognition model based on the spectral data, principal components analysis (PCA) coupled with artificial neural network (ANN) was used. The results showed that the PCA-ANN model could diagnose the infected plants and pathogen species with accuracy of 93-100% for test set samples. In 96 hours after inoculation, in addition to the non-destructive diagnosis of early blight of tomato plant based on Visible/Near-Infrared Spectroscopy and Principal Components Analysis- Artificial Neural Network Prior to Visual Disease Symptoms. Journal of Agricultural Machinery 12 (1): 81-94.

Keywords: Early blight, NIR spectroscopy, Principal components analysis, Tomato plants

Introduction

Tomato (Solanum lycopersicum L.) is one of the most popular plants in the world and is grown in a wide range of climates (Song et al., 2015). Tomatos are widely consumed because of its high nutritional value and are a well-known source of vitamins and minerals. They can be eaten as raw vegetables or processed products (Sigmund and Gustav, 1991; Minich et al., 2019). However, diseases can affect the yield and quality of tomato fruits

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during the growing season (Chaerani and Voorrips, 2006).

Early blight is a serious disease in tomato growing regions and has been reported under a wide range of climatic conditions. This disease weakens tomato plants and increases susceptibility of the plants to infection (Adhikari et al., 2017; Zhang et al., 2018). Leaf spots and leaf drop caused by early blight, reduce the photosynthetic area and increase the imbalance between nutrient demand and nutrient supply (Ding et al., 2019). Failure to control early blight at the right time leads to foliar damage, the serious losses of the yield and quality, and excessive consumption of fungicides in tomato production. Therefore, early diagnosis and control of this disease has great economic importance (Ershad, 2009; Adhikari et al., 2017).

Species of the genus *Alternaria* causes early blight in tomato plants. *Alternaria solani* and *A. alternata* are the most important pathogenic species of the genus *Alternaria* in many countries such as Iran (Ershad, 2009; Zhang et al., 2018). These two species are different in terms of the secreted enzymes involved in pathogenesis. Morphologically, *A. alternata* produces small spores and *A. solani* produces larger spores than those because of *A. alternata*. In tomato plants, pathogenicity of *A. alternata* is lower than that of *A. solani* (Simmons, 2000).

Because of climatic conditions of tomato cultivation, high humidity and moderate temperatures may spread early blight, especially in the southern and northern regions of Iran (Ershad, 2009; Babagoli and Behdad, 2012). As mentioned above, different chemical fungicides are used to control early blight. Early diagnosis of this disease can reduce the consumption of fungicides. On the other hand, identifying the disease before its incidence allows the application of biological fungicides to prevent the spreading of the disease agents (Zitter et al., 2004).

Plant diseases, are usually diagnosed by visual assessments or common laboratory methods. Common diagnostic techniques such as polymerase chain reaction (PCR), enzyme linked immune sorbent assay (ELISA), and fluorescence in situ hybridization (FISH) are destructive, time-consuming, and expensive. In addition, such diagnostic techniques require highly skilled technicians and advanced equipment (Xie et al., 2015; Ghanei Ghooshkhaneh, 2018).

Some non-destructive methods have been used to classify, forecast, diagnose or warn the occurrence of crop diseases, and various models have been developed for these non-destructive techniques. Near-infrared (NIR) spectroscopy as an advanced and innovative technology utilizes the spectral range from 780 to 2,500 nm (12,800 cm$^{-1}$–4,000 cm$^{-1}$) and provides internal structural information of organic materials in food, pharmaceutical, chemical, and petrochemical industries (Cen and He, 2007; Jamshidi et al., 2015). This technology coupled with the advanced mathematical and statistical methods has become a reliable, fast, and powerful non-destructive tool for analyzing the internal properties of organic materials (Tey et al., 2013; Nicolai et al., 2014).

NIR spectroscopy equipment (with a full spectral range) is expensive and its use in rapid detection systems depends on economic feasibility. The equipment with a narrower spectral range such as visible/near-infrared (Vis-NIR) spectroscopy equipment are low cost and more economically feasible for use in rapid and on-line detection systems (Mouazen et al., 2005). Some studies have confirmed the fitness of Vis-NIR or NIR spectroscopy for the classification of the leaves infected with citrus canker (Sankaran and Ehsani, 2013), diagnosis of the avocado leaves infected with laurel wilt (Sankaran and Ehsani, 2012), diagnosis of virus-infected soybean (Jinendra et al., 2010), diagnosis of huanglongbing in citrus orchards (Sankaran et al., 2011), and prediction of disease ratings for leaf gall in sugarcane clones (Purcell et al., 2009). However, relatively few reports have been found about the non-destructive diagnosis of crop diseases before the onset of symptoms. No reports have been found about the non-destructive diagnosis of
early blight on tomato plants before appearing visual symptoms using Vis-NIR or NIR spectroscopy.

This research aimed to evaluate the feasibility of non-destructive method of Vis-NIR spectroscopy for diagnosis of early blight diseases (A. solani and A. alternata, as the main agents in tomato plants in Iran) in the primary stages of the disease incidence before occurrence of visual symptoms. Moreover, different PCA-ANN models were also developed for different times of establishment and progression of pathogens to select optimum diagnosis models for diagnosing the disease and discrimination of pathogen type.

Material and Methods
Pathogenicity on tomato plants

Susceptible tomato seedlings (cv. Peto Early CH), planted in trays containing peat moss, were transferred to 1.5-liter pots in four-leaf stage. Ten milliliters of spore suspension of each of isolates of A. solani and A. alternata were prepared with sterile distilled water. Using a hemocytometer, the concentration of the suspensions was adjusted to $10^5$ and $10^6$ conidia per milliliter for A. solani and A. alternata, respectively. Spores were suspended in sterile distilled water. Plants were inoculated with conidia suspensions one month after transplanting. Each plant was inoculated again after 24 hours. The control treatment leaflets were sprayed with sterile distilled water. The inoculated plants were incubated at 20-22°C and 95% relative humidity (Rotem, 1994; Fulton et al., 1995). Figures 1(a) and 1(b) show the symptoms of the disease in the leaves inoculated with A. alternata and A. solani 10 to 12 days after inoculation.

![Symptoms of the disease in A. solani–inoculated leaf (a) and A. alternata–inoculated leaf (b) 10 to 12 days after inoculation.](image)

Spectral data collection

Spectroscopy System

The Vis-NIR spectral data of tomato leaves were acquired using a V700 UV-Vis-NIR spectrophotometer (OPTC, Co., Iran) equipped with a CCD sensor (Toshiba, Ltd., Japan) that can operate in the spectral range of 350-1,100 nm at the resolution of 1.8 nm. The light source was a 120W tungsten halogen lamp and the spectroscopy mode was reflectance one. Two optical fibers, which had a 45-degree angle with the leaf sample, were used to guide the light from the source to the leaf and from the leaf to the spectrophotometer.

Samples and Spectroscopy times

Collecting the spectral data was performed at four times after inoculation, including two days (48 hours), three days (72 hours), four days (96 hours), and five days (120 hours) after inoculation. Occurrence of symptoms of
early blight on tomato plants depends on many factors and under the best condition; the symptom is visualized for five to seven days after conidia establishment on the leaves (Sherf and MacNab 1986; Chaerani et al., 2007).

The lower and upper leaves of each plant were excluded from the experiment. For each pathogenic species, the spectral data were acquired from 50 leaves of the infected plants (from 4-6 plants), in each day after inoculation. On the fifth day (120 hours after inoculation), five spectral samples of the leaves infected with A. solani were lost because of incorrect spectra collection, and the total number of the samples infected with A. solani in this day was 45. In each day of spectroscopy, along with acquiring the spectra from the inoculated samples, the spectral data from the leaves of two healthy plants (control treatment) were also acquired (approximately 23 leaves per day). In total, the number of spectral samples of healthy leaves was 91. Therefore, the total number of samples on each of the second, third, and fourth days after inoculation was 191, and in the fifth day was 186. For each leaf sample, five measurements from five different points were obtained. The average of these five spectra was used as a representative spectrum for one leaf sample.

**PCA-ANN models**

In this experiment, the ANN method was used for the classification of A. alternate-inoculated, A. solani-inoculated, and healthy leaves. An ANN is a non-linear computing model inspired by biological neural networks (Salchenberger et al., 1992; Kia, 2010; Castro et al., 2017). ANNs modeling technique have been widely used for prediction and classification based on the spectral data (Mireei et al., 2010; Pan et al., 2016; Dai et al., 2015; Yoplac et al., 2019).

Multilayer feed forward network with backpropagation (BP) learning algorithm, which is the most popular neural network, was used for the recognition of the leaf samples. One BP network is a feed forward multilayer perceptron network that consists of one input layer with the neurons as independent variables, one or more hidden layers, and one output layer with the neurons as a dependent variable (leaf classes in this study) (Kia, 2010; Omid et al., 2010). In this study, a single-hidden layer ANN was established for classification. The transfer function was tansig, the training function was trainscg, and epoch was 1,000. Wavelengths shorter than 400 and longer than 900 nm were eliminated to reduce the noise and thus, the spectral range of 400 to 900 nm was used for developing the model.

The spectral data in the range of 400-900 nm was used as the input layer in ANN, but they were not directly used because of the large number of the data for each spectrum sample. In order to reduce the data in each spectrum, PCA was used. PCA is a well-known technique for the data mining and is commonly used in spectroscopy (Wold et al., 2101). PCA is an orthogonal linear transformation that transforms the spectral data to a new coordinate system whose axes are the PCs. In this transformation, the greatest variance of the data comes to lie on the first coordinate (called the first principal component), the second greatest variation on the second PC, and so on. This process continues until the cumulative variance of the principal components is equal to 100% of the variance of the original data. In PCA, the data components that have the greatest effect on the variance, are selected and can be used instead of the original data and reduce the data volume (Nicolai et al., 2007). It is clear that the first component, then the second component, and the subsequent components have the greatest impact on recognition, respectively. The optimum number of PCs in the PCA-ANN models was chosen based on the cumulative explained data variance (Brown et al., 2005).

For the classification of the leaves in each day based on PCs, the samples were divided into a training (70%), validation (15%), and test (15%) subsets, randomly. The training datasets were used to fit the model, and the validation datasets were used to stop the training ones and avoid overfitting when the error in the validation datasets increases. The
test datasets were used to evaluate the model fitted at the training stage. In this paper, the developed models were also evaluated by training and validation subsets, in addition to evaluation by test subset.

The optimum number of neurons in the hidden layer was determined by trial and error and examining several networks with the different number of neurons in the hidden layer, and finding the optimum model. A 3-byte binary code was assumed for the output vectors of three output neurons (Kia, 2010; Omid et al., 2010). Therefore, the output vectors (100), (010), and (001) were denoted as the healthy leaf, *A. alternata*-inoculated leaf, and *A. solani*-inoculated leaf, respectively.

In the PCA-ANN models, of the variance explained by PCs should be at least 85% of variance of the original data (Mireei et al., 2010). The models with the lower number of PCs have lower classification accuracy, while using the higher number of PCs makes more complex models without a significant difference in the discrimination power (Nicolai et al., 2007). In this study, the maximum number of PCs as the input for ANN was considered 10. Finally, the optimum number of PCs as the input for ANN was selected by trial and error. These PCs were selected instead of the original spectral data.

For each time after inoculation (48 hours, 72 hours, 96 hours, and 120 hours), one PCA-ANN model was developed to discriminate healthy, *A.* -infected and *A. solani* -infected leaves. In this paper, principal components analysis and BP-ANN were carried out using Matlab12.

The procedure of this study is shown in Figure 2.

---

**Fig.2.** Research procedure
Results and Discussion

Effect of early blight pathogens and time on the absorbance spectra

Figures 3(a), (b), (c), and (d) show the mean absorbance spectrum of healthy, A. alternata–inoculated, and A. solani–inoculated leaves in 48 hours, 72 hours, 96 hours, and 120 hours after inoculation at the wavelength range of 400-900 nm, respectively. For the better interpretation of spectra, absorbance values (Log (1/R)) of spectra are shown instead of raw spectra in Figure 2 (Azadshahraki et al., 2018).

All spectra had two broad peaks around 470 nm and 680 nm, which were due to the chlorophyll of the photosystem I and II reaction centers (Taiz and Zeiger, 2002). In 48 hours and 72 hours after inoculation, the mean absorbance spectra were clearly very similar. As mentioned above, spores of A. solani are larger than those of A. alternata. In 48 hours after inoculation, the absorption (height of spectrum) of A. solani samples was lower than that of other samples and this might have been due to the greater light reflection because of large spores. Over time, as the spores multiply and grow, the reaction between spores and leaves increases, and the light absorption (height of the spectrum) increases in both species of diseases. At other times after inoculation, the absorption (height of spectrum) of A. solani samples was lower than that of other samples and this might have been due to the greater light reflection because of large spores. Over time, as the spores multiply and grow, the reaction between spores and leaves increases, and the light absorption (height of the spectrum) increases in both species of diseases. At other times after inoculation (96 hours and 120 hours after inoculation), absorbance spectra of the inoculated leaves changed and the shape of the second peaks was quite different from that of the second peaks of spectra in the second and third day after inoculation. The height of the mean absorbance spectra of the inoculated leaves was increased in the fourth and fifth days after inoculation, and these means were higher than the mean absorbance spectrum of healthy leaves. These changes in the spectra of the infected leaves and the differences between the spectra of the infected and healthy leaves in fourth and fifth days could be due to the impact of diseases on the leaves and might have been effective in discriminating the infected leaves. The absorption increment in spectra of both A. alternata–infected and A. solani–infected leaves in 96 hours and 120 hours after inoculation indicated that early blight disease increased the absorption of chlorophyll over time, and this increment around 470 nm was more than around 680 nm. In general, the height changes in A. solani–infected spectrum was more than that in A. alternata–infected spectrum. Because the pathogen (Alternaria spp.) is a necrotrophic fungus, within 48 to 72 hours after inoculation, it is possible that the fungal spores could be plasmolyzed and the contents of them could be transferred to the host cells. The reduction in the spore volume caused in order that the spectrum of the inoculated leaves could be closer to the control treatment leaves. However, 72 hours after inoculation, the intracellular host changes were begun, and the spectrum absorption increased in the infected leaves. Research has shown that members of the genus Alternaria cause quiescent infections, in which the fungus enters the tissue where it remains dormant until changed conditions favor infection (Thomma, 2003).

Diagnosis of healthy and infected plants at each time after inoculation

Tables 1, 2, 3, and 4 show the results of the classification of training, validation and test sample sets of healthy, A. alternata-infected, and A. solani-infected leaves of tomato plants for 48 hours, 72 hours, 96 hours, and 120 hours after inoculation using Vis-NIR spectroscopy (400-900 nm) and the PCA-ANN model. According to these Tables, the optimum developed PCA-ANN model for each time after inoculation had the specific number of PCs as well as neurons in the hidden layer. All selected PCs could explain more than 99% of the variance of the original data and had high power of discriminating the infected leaves. In the second and third day after inoculation, the models were more complex (had more PCs and more hidden layer neurons).
As mentioned above, with the impact of pathogens on the inoculated leaves and deformation of their absorbance spectra over time, fewer PCs were needed to develop the best model. At all times after inoculation, the developed models were able to accurately discriminate healthy, *A. alternata*-infected, and *A. solani*-infected leaves from each other. In 48 hours, 72 hours, and 120 hours after inoculation, the discrimination accuracy were 98.5%, 99.2%, and 98.5% for training sample sets and 96.6%, 100%, and 100% for validation sample sets. These models were used for diagnosis of test sample sets, and accuracy of 100%, 93.1%, and 96.4% were obtained. In 96 hours after inoculation, the discrimination accuracy for all subsets was 100%. In other words, Vis-NIR spectroscopy with the developed PCA-ANN models could diagnose early blight-infected leaves and the type of pathogen at the accuracy of 93.1%-100% of test samples in the early stages of disease before visual symptoms. The lowest accuracy in the test samples was related to 72 hours after inoculation, which the absorbance spectra of healthy samples and both infected samples were more similar. For all samples, discrimination accuracies were 98.4%, 98.4%, 100%, and 98.4% in the second, third, fourth, and fifth days after inoculation, respectively. The results showed that at all times after inoculation and in all subset samples, there was no error in the discrimination of the leaves infected with *A. solani* pathogen (which is
more pathogenic and more damaging in tomato plants) and healthy leaves. Occurrence of symptom of early blight disease in tomato plants depends on many factors, including temperature, relative humidity, and host sensitivity. Two days after infection, *Alternaria conidia* penetrates the cells by producing germ tube. After penetration and colonization, the pathogen degrades the host cell wall by enzymes, and the lesions become visible three days after infection. Under the best condition, the symptom visualized in five to seven days after the establishment of conidia in the leaves (Sherf and MacNab 1986; Chaerani *et al.*, 2007). After this relatively short period, the disease cycle allows a polycyclic infection and rapidly spreads in all leaves. Early diagnosis can be prevented disease incidence before colonization and spore production, allowing a polycyclic infection (Sherf and MacNab 1986).

### Table 1- Diagnosis results in training, validation and test sets of optimum PCA-ANN model at 48 hours after inoculation

<table>
<thead>
<tr>
<th>The optimum number of PCs</th>
<th>The optimum number of neurons in hidden layer</th>
<th>Subsets</th>
<th>Leaf class</th>
<th>Diagnosis results</th>
<th>Accuracy (%)</th>
<th>Overall accuracy (%)</th>
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</thead>
<tbody>
<tr>
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<td></td>
<td></td>
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<td>Healthy</td>
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</tr>
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<td><em>A. solani</em></td>
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### Table 2- Diagnosis results in training, validation and test sets of optimum PCA-ANN model at 72 hours after inoculation

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<th>Subsets</th>
<th>Leaf class</th>
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<th>Accuracy (%)</th>
<th>Overall accuracy (%)</th>
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<td></td>
<td>No.</td>
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<td><em>A. solani</em></td>
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<td><em>A. solani</em></td>
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<td>9</td>
<td>Test</td>
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<td></td>
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Table 3- Diagnosis results in training, validation and test sets of optimum PCA-ANN model at 96 hours after inoculation

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<th>Accuracy (%)</th>
<th>Overall accuracy (%)</th>
</tr>
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<td>100</td>
<td>100</td>
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<td>Training A. alternata</td>
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<td>A. solani</td>
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<td>33</td>
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<td>Healthy</td>
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<tr>
<td>Validation A. alternata</td>
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<td>A. solani</td>
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<td>0</td>
<td>6</td>
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<td>Healthy</td>
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<td>0</td>
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<td>Test A. alternata</td>
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<td>A. solani</td>
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</table>

Table 4- Diagnosis results in training, validation and test sets of optimum PCA-ANN model at 120 hours after inoculation

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<th>Diagnosis results</th>
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<td>A. solani</td>
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<td>Healthy</td>
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<td>14</td>
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<tr>
<td>Validation A. alternata</td>
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<td>A. solani</td>
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<td>0</td>
</tr>
<tr>
<td>Test A. alternata</td>
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<td>0</td>
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<td>All</td>
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</tbody>
</table>

In present study, the accuracy of using Vis-NIR spectroscopy and the PCA-ANN model for early diagnosis of the tomato leaves infected with early blight was close to that of diagnosis of A. alternata in the eggplant leaves (over 88.46% in the testing sets) using the hyperspectral image technique reported by Xie and He (2016). Yin and Zhao (2013) reported the accuracy of 80.68% for recognition of early blight in tomato plants using the hyperspectral data and the support vector machine. Atherton et al. (2015) reported that hyperspectral spectroscopy could discriminate more heavily the potato plants diseased with early blight (A. solani) from healthy potato plants in different growth stages. Atherton et al. (2017) used hyperspectral remote sensing spectroscopy for advanced diagnosis of early blight (A. solani) in potato plants prior to visual disease symptoms, and reported that the technique could distinguish moderately the diseased plants from healthy and minimally diseased plants. An investigation of the potential of using hyperspectral imaging for diagnosing early blight and late blight diseases in tomato leaves by Xie et al. (2015) showed that using a hyperspectral imaging technique and extreme learning machine (ELM)
classifier model or successive projection algorithm (SPA) could excellently diagnose the diseases at the accuracy of 97.1-100% in the testing sets. Diagnosis accuracy of present study for test set samples (93.1-100%) was close to the results reported by Xie et al. (2015). However, different studies for non-destructive diagnosis of diseases have different results because of different instruments, stage of diseases, plant types and varieties. Because of the high cost of hyperspectral imaging equipment and good results of present study, Vis–NIR spectroscopy can be recommended for diagnosis of early blight disease prior to visual symptoms. The results of this research compared to other studies are summarized in Table 5.

### Table 5- Comparison of the performance of early and nondestructive diagnosis of early blight disease in this study with other studies

<table>
<thead>
<tr>
<th>Research</th>
<th>Vegetable</th>
<th>Accuracy (%)</th>
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<tbody>
<tr>
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<td>93.1-100</td>
</tr>
<tr>
<td>Xie et al., 2015</td>
<td>Tomato</td>
<td>97.1-100</td>
</tr>
<tr>
<td>Gold et al., 2020</td>
<td>Potato</td>
<td>89.95</td>
</tr>
<tr>
<td>Xie and He, 2016</td>
<td>Eggplant</td>
<td>88.46</td>
</tr>
<tr>
<td>Yin and Zhao, 2013</td>
<td>Tomato</td>
<td>80.68</td>
</tr>
</tbody>
</table>

### Conclusion

This study evaluated the feasibility of utilizing Vis–NIR spectroscopy (range of 400-900nm) using a CCD spectrometer coupled with the PCA-ANN modeling method for early and non-destructive diagnosis of early blight disease in tomato plants and diagnosis of type of pathogen (A. alternata and A. solani) before the appearance of the symptoms. The results of this study indicated that, when optimum PCs and optimum number of neurons in the hidden layer of ANN were selected, the PCA-ANN model could accurately diagnose the infected plants and type of pathogen (accuracy of 93.1-100%). Over time, the shape of the infected spectra changed and this change was effective in diagnosing the infected leaves. At all times after inoculation, the developed models could discriminate A. solani-infected plants from healthy leaves at the accuracy of 100%. This was a noticeable result because of more pathogenicity and more damage of A. solani species. On fourth day after inoculation, Vis-NIR spectroscopy combined with the PCA-ANN computing method could diagnose the infected leaves and type of pathogen without any error by the simpler model. Therefore, it was concluded that Vis-NIR spectroscopy could be utilized for rapid and non-destructive early diagnosis of early blight on tomato plants before visual symptoms without any plant sample preparation. It is recommended that diagnosis of other causes of tomato leaf spots, including manganese deficiency, and fungi of Septoria sp. and Cercospora sp., in which some cases have similar symptoms to early blight, be evaluated by NIR spectroscopy in the future research.

### Acknowledgement

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### References


تشخیص بیماری لکه‌هجو گوجه‌فرنگی بر پایه طیف‌سنجی مرئی/ فروسرخ نزدیک و تجزیه مؤلفه‌های اصلی - شبکه عصبی مصنوعی قابل از ظهور علائم بیماری
فرزاد آزادشهرکی 1، کسری شریفی 2، بهاره جمشیدی 3، روح الله کریم‌زاده 4، هانیه نادری 5
تاریخ دریافت: 1399/09/32
تاریخ پذیرش: 1399/11/27
چکیده
تشخیص بیماری قبل از ظهور علائم می‌تواند اثر را به کاهش دهد و کیفیت محصول را افزایش دهد. این امر همچنین مصرف سموم شیمیایی، مشکلات زیست‌محیطی و هزینه تولید را کاهش می‌دهد. هدف از انجام این تحقیق، تشخیص غیر تخریبی بیماری لکه‌هجو گوجه‌فرنگی و همچنین تشخیص مهندسی عاملی بیماری آن (A. solani، A. alternate) از یکدیگر در مرحله پیش‌بازاری، قبل از بروز علامت ظاهری، با استفاده از طیف‌سنجی مرئی/ فروسرخ نزدیک (0.400-0.900 نانومتر) بود. داده‌های طیفی از برگ‌های گیاهان آلوده به A. solani و A. alternate در 0.4، 23، 59 و 330 ساعت بعد از تلقیح بیماری استخراج شدند. به منظور توسعه مدل‌های تشخیص بر اساس داده‌های طیفی، از تجزیه مؤلفه‌های اصلی (PCA) و شبکه عصبی مصنوعی (ANN) استفاده شد. نتایج نشان داد که مدل PCA-ANN بهترین نتایج را داشت. این مدل می‌تواند بیماری لکه‌هجو گوجه‌فرنگی را قبل از ظهور علائم با دقت بیش از 90 درصد تشخیص دهد.

واژه‌های کلیدی: تجزیه مؤلفه‌های اصلی، طیف‌سنجی فروسرخ نزدیک، گوجه‌فرنگی، لکه‌هجو

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Investigation on the Capability of GreenSeeker Sensor in Predicting Nitrogen Status and Fractional Vegetation Cover of Spinach Crop

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Abstract
Fractional vegetation cover (FVC) and normalized difference vegetation index (NDVI) are the most important indicators of greenness and have a strong correlation with green biomass. The objective of this study was to evaluate a hand-held GreenSeeker (GS) active remote sensing instrument to estimate NDVI and FVC in the spinach plant. In this study, the color indices of the G-B index and Excess Green (ExG) were used as color vegetation indices to discriminate leaves from soil background. During 28 to 44 days after emergence (DAG), the results showed good correlations between chlorophyll yield and NDVI (R = 0.61 to 0.91), and the correlation between NDVI of GS and biomass was significant. In addition, in this growth stage, the results showed a good coefficient of correlation between NDVI of GS and FVC (R = 0.67 to 0.82). In assessing the nitrogen rate on the NDVI of GS, the results showed significant differences only at the short period of growth stage (28 to 36 DAG). The results revealed that GreenSeeker performed well for estimation both chlorophyll and biomass yield of spinach crop and it could be used as a suitable instrument for estimation of leaf area index in the middle of the plant growth period.

Keywords: Canopy, Chlorophyll, Optical sensor, Segmentation

Introduction
The main challenges for global food security and sustainable development are how to increase food production whereas improving resource use efficiencies and reducing risks of environmental contamination (Guo et al., 2010; Chen et al., 2014). Blanket fertilizer nitrogen (N) recommendations lead to low N use efficiency (NUE) due to field-to-field variability in soil N supply (Cao et al., 2016). Traditionally, pre-plant nitrogen requirements have been estimated by using soil samples and crop yield levels from previous years. The estimated rate is then applied uniformly to the field (Sawyer, 1994). Many farmers often apply fertilizer N in doses higher than the blanket recommendations to ensure that there is no yield loss because of N deficiency (Purba et al., 2015). Using fertilizer over plant demand may result in surface runoff and pollution of streams. Under-application of nitrogen may diminish crop production and result in low economic returns to the producer (Miao et al., 2011).

Advances in technology have led to development of active remote sensing systems that are now available commercially (Inman et al., 2007). In principle, they can be mounted on a VRT fertilizer system that is used to vary the amount of fertilizer for a given area in real-time (Williams, 2006).

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Recently, farmers using precision agriculture tools and technologies such as leaf color chart (LCC), chlorophyll meter (SPAD), GreenSeeker, and real-time on-the-go optical sensing measurements (OPM) based variable rate (VRT) fertilizer application. These tools and technologies can reduce under or over-application of N (Boyer et al., 2011; Bagherpour et al., 2017). Raun et al. (2002) analyzed optical sensing and VRT for Oklahoma, USA winter wheat production. They showed that the extra income owning to an increase in NUE (N use efficiency) can cover the expected costs of the technology and that OPM-based VRT would be most profitable in areas of high spatial variability. Leaf color chart has been used successfully to optimize fertilizer N application in wheat and rice (Ladha et al., 2007). SPAD chlorophyll meter was confirmed to provide a quick, simple, and nondestructive estimation of leaf chlorophyll content (Chapman and Barreto, 1997). The use of SPAD with grain (Ramesh et al., 2002) and vegetables (cabbage and carrot) has recently been tried (Westerveld et al., 2004). Normalized difference vegetation index (NDVI) as a spectral vegetation index is useful for acquiring crop information indirectly, such as productivity potential, photosynthetic efficiency, and potential yield (Raun et al., 2001; Inman et al., 2007, Thind et al., 2017).

Both NIR and red irradiance are strongly influenced by plant cover. NIR irradiance increases and red irradiance decreases with increasing plant cover. Given these relationships, NDVI from vegetated surfaces is heavily influenced by chlorophyll content in the vegetation. A deficiency in nutrients such as nitrogen decreases pigment formation, which subsequently increases red reflectance (Jones et al., 2007).

NDVI is a broadband index that has a good correlation with green biomass and leaf area index (Penuelas et al., 1994). Raun et al. (2001) showed that the expected yield determined from NDVI had a strong relation with actual grain yield in winter wheat. Bausch and Diker (2001) investigated the remote sensing techniques to increase the nitrogen use efficiency of corn. Their results showed that the NIR could well predict the plant N at the 9-leaf to 12-leaf crop growth stages. However, the effects of the soil background on reflectance had a negative effect on these relations.

Site-specific N management strategy using GreenSeeker™ optical sensor (GS) was evaluated in dry direct-seeded rice (DDSR) in north-western India. N use efficiency was improved by more than 12% when N fertilizer management was guided by GS as compared to when the general N fertilizer recommendation was followed (Ali et al., 2014).

Sharma et al. (2011) observed that high N use efficiency in irrigated wheat grown in Northwest India can be achieved by replacing general fertilizer recommendation with an optical sensor-based N management strategy. Enciso et al. (2017) evaluated current commercially available sensor technology for use in a ground-based platform for plant phenol typing and crop management decisions. Results showed that the Normalized Difference Vegetation Index (NDVI) data collected using the GreenSeeker sensors were more consistent and presented less variability when compared to the Decagon SRS sensor.

Currently, most of the methods available for measuring leaf area index are based on manual measurements, which are time-consuming, laborious, and destructive (Fuentes et al., 2014). Aerial and ground-based remote sensors have emerged as an important source of information on vegetative canopy through vegetation indices. The NDVI is related to the quantitative biomass and can be used to monitor vegetative growth and to determine biophysical variables such as leaf area (Junges et al., 2019). Ter-Mikaelian and Parker (2000) estimated the biomass of white spruce seedlings with vertical photo imagery. The accuracy of this technique was comparable to the traditional methods using seedling basal diameter. Lukina et al. (1999) evaluated the use of a digital image to estimate vegetation coverage and a multispectral radiometer to
measure NDVI index in winter wheat. The results of this study showed a strong correlation between NDVI and vegetation coverage ($r^2 = 0.66$ to 0.96). In addition, NDVI have a strong correlation with dry biomass ($r^2 = 0.52$) and with nitrogen content ($r^2 = 0.66$).

Spinach (*Spinacia oleracea*) is a leafy green flowering plant native to central and western Asia. Its leaves are a common edible vegetable consumed either fresh, or after storage using preservation techniques by canning, freezing, or dehydration. Spinach is rich with vitamins such as vitamin C, vitamin A, vitamin E, minerals like magnesium, manganese, iron, calcium, and folic acid. Spinach is also a good source of chlorophyll, which is known to aid in digestion (FAO, 2020). Along with these advantages, to increase crop yield, it needs high N fertilizer and in the commercial production of this plant, the recovery of N is poor, which may result in environmental contamination. To increase spinach yield and decrease its environmental consequence, there is a need to optimize nitrogen consumption (Navarrete et al., 2016). Therefore, this study aimed to investigate the relationship of nitrogen rate, leaf area index, and biomass with NDVI to find an effective, fast and non-destructive way to estimate leaf N in spinach plants and to test the potential linkage between FVC and biomass with NDVI of GS.

**Materials and Methods**

**Plant material and experimental setup**

This study was conducted at the agricultural research station, faculty of agriculture, university of Bu-Ali Sina (35°1’ N, 48°31’ E, 1690 m alt) during the 2019 growing season. This site has a semi-arid and cold climate, an average annual rainfall of 333 mm and an average temperature of 24° C in the warmest month (Hamzei et al., 2012).

Spinach seeds ‘native cultivar of Nahavand’ was planted on March 10th with 20 plants per m² density. The experiment was laid out as Randomized Complete Block Design with three replications including four levels of nitrogen (0, 75, 150, and 300 kg ha⁻¹). Each experimental unit contained six lines a distance of 30 cm and a length of 6 m, and the distance between each block was 1 m. Three random soil sample cores were obtained from each plot prior to fieldwork using a 3 cm diameter hand probe to a depth of 0-15 cm for potassium (K), phosphorus (P), pH, and organic matter and 0-30 cm in depth for nitrate. Soil samples were air-dried, ground to pass through a 2 mm screen, and were mixed before analysis for soil pH, available P, K, and organic matter. Soil pH was measured in a 1:1 ratio of soil to deionized H₂O solution (Watson and Brown, 1998), P by the Olsen method (Olsen et al., 1954), K was analyzed using the 1-N ammonium acetate method (Thomas, 1982), soil nitrogen was determined using O’Brain and Flore (1962) method and organic matter was measured using the loss following ignition method (Schulte and Hopkins, 1996). Plots in all experiments were irrigated with flood irrigation. The result of soil analysis was presented in Table 1.

<table>
<thead>
<tr>
<th>Soil characteristic</th>
<th>Quantity</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Texture</td>
<td>sandy clay loam</td>
<td>-</td>
</tr>
<tr>
<td>pH</td>
<td>7.15</td>
<td>-</td>
</tr>
<tr>
<td>Organic carbon</td>
<td>2.38</td>
<td>%</td>
</tr>
<tr>
<td>Organic matter</td>
<td>4.10</td>
<td>%</td>
</tr>
<tr>
<td>Total N</td>
<td>0.20</td>
<td>%</td>
</tr>
<tr>
<td>Available P</td>
<td>57.84</td>
<td>mg kg⁻¹</td>
</tr>
<tr>
<td>Available K</td>
<td>703.30</td>
<td>mg kg⁻¹</td>
</tr>
</tbody>
</table>

**NDVI and SPAD Value Measurements**

Canopy reflectance was measured during 20 to 56 days after emergence with a
GreenSeeker hand-held optical sensor unit (Trimble Navigation Ltd., Sunnyvale, California, USA) over 12 plots of field. According to the Instructions for Use (Figure 1), the GreenSeeker was held at 65 cm above the crop canopy using an adjustable shoulder harness. Readings were taken for the defined area of each plot every four days throughout the experimental period. Spectral measurements were collected from each plot by moving the sensor across the center of each plot with an area of 1.8×2 m². To analyze the chlorophyll content of leaves, leaf samples were taken from areas located at both sides of each plot with a length of 1.5 m along the length. The SPAD readings were taken as an average of three different leaf readings located in the middle to the upper level of the plant excluding the midrib. In this study, a portable chlorophyll meter SPAD-502 (Minolta Co., LTD. Japan) was used to assess the nitrogen status of spinach leaves at various growth stages.

**Fig.1. The Handheld Greemseeker and height of the sensor**

**Determination of Chlorophylls and total Carotenoids in Leaves**

After reading the NDVI of the central section of each plot with the GreenSeeker sensor and imaging with the visual imaging system, one leaf located in the middle to the upper level of the four plants at the inside of the two side sections were hand-harvested. The spinach samples were placed in plastic bags, weighed, labeled, carefully closed, and then refrigerated for later processing in the laboratory. In the laboratory, samples were washed, frozen, and dried. The chlorophyll and carotenoid pigments were extracted in 99% acetone by macerating the leaves with a mortar and pestle. The absorption of the extracts at wavelengths of 470 nm, 645 nm, and 664 nm was measured by spectrophotometer UV/visible (Varian-carry 100) according to the spectrophotometric method of Inskeep and Bloom (1985).

**Measuring crop biomass**

The main objective of this measuring was to estimate final crop biomass by NDVI of GS in the period of growth stages. At each sampling location, spinach biomass was measured by cutting all plants at ground level from within a 1-m² quadrat at the end of growth stages. Biomass samples were transported to the laboratory where fresh weight was recorded.

**Acquiring visual images**

After reading, the NDVI of the sample area using the GreenSeeker sensor, a corresponding visual image was acquired using a Samsung digital camera with a resolution of 8 Mpixels (3264×2248). The imaging system was mounted to a pole on a platform held horizontally 1.5 m above the ground. For each plot, three photographs were taken and the area photographed was approx. 1.8×2 m². All the images were taken between
at cloudy conditions or on areas shaded with a sheet to eliminate the effect of sunlight on image quality. All images were saved in JPEG-Format. The images were processed by LabView 2014 (National Instruments Corporation, Austin, TX, USA) and MatLab 2016a (MathWorks, Inc., Natick, Massachusetts, US).

**Image segmentation**

This section aims to separate the soil background from the canopy representing green plant parts. This allowed determining the ground cover of living plant leaves. Several methods have been developed for segmenting crop canopy images. The common segmentation technologies used for this purpose are color index-based segmentation, threshold-based segmentation, and learning-based segmentation (Hamuda et al., 2016). Most researchers have used color to separate soil from a plant (Meyer and Camargo-Neto, 2008; Kirk et al., 2009). In a recent study at the early stage of growing, according to Woebbecke et al. (1995), the G-B (green-blue) index was used as a color index-based segmentation to discriminate leaves from soil background. Nevertheless, in the flowering period, the Excess Green (ExG), according to Equation 1, the index showed good results than G-B (Soontranon et al., 2014). Because of unreliable results in the auto threshold, fixed threshold values were used for each series of images, which were taken under similar light conditions. After segmentation of images, the fractional vegetation cover (FVC) was calculated as the ratio of the number of pixels of all vegetation to the total number of pixels in the image (Song et al., 2015). The temporal segmentation results of the crops were shown in Figure 2. In this Figure, it can be observed that the color indices of G-B and ExG perform well in segregating this crop from its background.

![Fig.2. The segmentation results of the crop at a different stage of growth. a and b are early stage, c and d are the late stages of growing](image)

\[
\text{ExG} = 2G - (R + B) \tag{1}
\]

**Results and Discussion**

**Changing NDVI during growing stages**

The change of GS readings in the canopy of spinach was shown in Figure 3. The GS readings for all treatments (N0 to N300) increased until 44 DAG and then decreased. With increasing the length of growth period, spinach leaves with a high concentration of N fertilizer always had higher GS values than those with a low concentration of N fertilizer. For all days of growth period value of
treatment, N300 was higher than that of other N treatments. These changes indicated that it is possible to predict the nitrogen level of the canopy for all days of the growth stage. This Figure also shows that for all nitrogen levels, the GS reading peaking at 44 DAG. After 44 days, for all treatment, GS readings were dramatically declined due to the maturation of plants. Changes in SPAD readings in leaves of spinach were shown in Figure 3. Similar to GS readings, the SPAD readings have high variance at the early stage of plant growth, whereas at the late stage of growing, these data have low variance. Data collection overlapped with plants' anthesis, which interfered with the GreenSeeker™ NDVI values and decreased readings in the later phases of growing (Basyouni et al., 2015). Additionally, the flowering progress might have consumed leaf N, which decreased sensor readings at later stages (Lawrie and Wheeler, 1974).

Liu et al. (2006) reported similar results for the SPAD reading changes during the growth stage of 25 to 35 days after sowing. However, they did not investigate the SPAD reading changes at the late stage of growth. Junges et al. (2019) studied a vineyard in Brazil using the GreenSeeker remote sensor and reported similar results for the GS readings. The index increases rapidly at first (September to November), followed by a relative stabilization (December to February), and decreases in the final stage (March to May).

Table 2 demonstrates the Pearson’s correlation coefficients between GreenSeeker NDVI and the other variables. These results showed that NDVI has a good correlation with chlorophyll yield and biomass with correlation coefficients (R) ranging from 0.61 to 0.91 and from 0.69 to 0.87, respectively. The highest correlation between these variables was obtained at the growth period of 32-40 days. After 44 days, nutrition deficiency in the plant leads to yellowing leaves. These changes in leaves color and preliminary mature of spinach plants can be the main reason for the decreasing of correlation coefficients between NDVI and these variables. This relationship concurs with work done by Raun et al. (1998) and Basyouni et al. (2016).

As Table 2 shows, NDVI correlations with leaf N and fertilizer rate were not significant (P < 0.05) at 20 and 24 DAG. This can be related to the small size of plants at the early stages of growth, which results in background noise interfering with the NDVI readings (Basyouni et al., 2015). As plants grew and filled the plots with time, these correlations were strong. This corresponds with the results of Wang et al. (2012), Dunn and Goad (2015), and Ali et al. (2020) showed a strong correlation between GreenSeeker NDVI readings and chlorophyll yield in geranium and ornamental cabbage and wheat.
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Table 2- Mean correlation coefficient of plots between GS NDVI- chlorophyll yield, NDVI - Biomass, and NDVI - FVC during the growth period

<table>
<thead>
<tr>
<th>Day After Emergence</th>
<th>NDVI vs. chlorophyll yield</th>
<th>NDVI vs. biomass</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>0.47</td>
<td>0.51</td>
</tr>
<tr>
<td>24</td>
<td>0.74**</td>
<td>0.53</td>
</tr>
<tr>
<td>28</td>
<td>0.88**</td>
<td>0.73**</td>
</tr>
<tr>
<td>32</td>
<td>0.90**</td>
<td>0.76**</td>
</tr>
<tr>
<td>36</td>
<td>0.91**</td>
<td>0.85**</td>
</tr>
<tr>
<td>40</td>
<td>0.86**</td>
<td>0.87**</td>
</tr>
<tr>
<td>44</td>
<td>0.61*</td>
<td>0.69*</td>
</tr>
<tr>
<td>48</td>
<td>0.41</td>
<td>0.45</td>
</tr>
<tr>
<td>52</td>
<td>0.42</td>
<td>0.46</td>
</tr>
<tr>
<td>56</td>
<td>0.42</td>
<td>0.46</td>
</tr>
</tbody>
</table>

*, **, representing correlation coefficient (r), significant at $P \leq 0.05$, $P \leq 0.01$, respectively.

NDVI correlations with biomass were also not significant at the early stage of establishment. In addition, there was no significant correlation between these variables at the last stage of plant growth. The decreasing NDVI values at the end of the cycle were expected due to the senescence and yellowing of the plant leaves. This result was similar to previous literature findings in dianthus (Basyouni et al., 2016) and grape (Junges et al., 2017).

Effects of fertilizer rate on NDVI

Table 3 shows GS readings during the growth followed linear trends as fertilizer rates increased. With increasing N rate, the linear trends of NDVI and leaf N rates were significant. Comparing the mean value of the GreenSeeker™ NDVI indicated that there are significant differences among N rates. However, after 44 DAG there are no significant differences between N treatments. For the early growth stage, the result of this study was similar to the result of Basyouni et al. (2016) that investigated the use of non-destructive sensors to assess nitrogen status in potted dianthus production. However, during the late growth stage, these results are in contrast to their finding.

Table 3- GreenSeeker™ NDVI means, and trend analysis at six dates of days after emergence (DAG) and five N fertilizer rates

<table>
<thead>
<tr>
<th>Total N applied (kg ha$^{-1}$)</th>
<th>20</th>
<th>24</th>
<th>28</th>
<th>36</th>
<th>44</th>
<th>52</th>
<th>56</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.415</td>
<td>0.430$^a$</td>
<td>0.441$^a$</td>
<td>0.390$^c$</td>
<td>0.690$^*$</td>
<td>0.575$^*$</td>
<td>0.525$^*$</td>
</tr>
<tr>
<td>75</td>
<td>0.415</td>
<td>0.481$^{ab}$</td>
<td>0.530$^b$</td>
<td>0.540$^e$</td>
<td>0.745$^*$</td>
<td>0.591$^*$</td>
<td>0.535$^*$</td>
</tr>
<tr>
<td>150</td>
<td>0.39</td>
<td>0.475$^{bc}$</td>
<td>0.535$^b$</td>
<td>0.635$^c$</td>
<td>0.752$^*$</td>
<td>0.620$^*$</td>
<td>0.565$^*$</td>
</tr>
<tr>
<td>300</td>
<td>0.385</td>
<td>0.515$^a$</td>
<td>0.595$^c$</td>
<td>0.710$^d$</td>
<td>0.761$^*$</td>
<td>0.625$^*$</td>
<td>0.575$^*$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total N applied (kg ha$^{-1}$)</th>
<th>20</th>
<th>24</th>
<th>28</th>
<th>36</th>
<th>44</th>
<th>52</th>
<th>56</th>
</tr>
</thead>
<tbody>
<tr>
<td>N.S</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*, **, linear (L) response across treatments at $P \leq 0.05$, $P \leq 0.01$, respectively. N.S: Non-Significant difference

Estimate FVC using NDVI of GS

The traditional method of estimating FVC is to harvest vegetation and measure all the one-sided leaf areas directly. In this study, the relation between FVC and GS NDVI was done to investigate the capability of GS to measure FVC in spinach. As Figure 4 shows, at the early stage of the growing period from 28 to 40 DAG, there were significant correlations between GS-NDVI and FVC extracted by the low-cost camera. However, before 28 and after 44 DAG there were no significant correlations between these variables. Figure 5 showed GS NDVI and FVC regression at 28, 40, and 52 DAG. As this figure showed, although the FVC was higher at the late growth stage, because of N deficiency in leaves the GS NDVI and FVC correlation was low. Results indicated that at the early stage of growth, the GS NDVI was a good index for the estimation
of canopy leaf area. Whereas at the late period of growing, it is not a good estimator of canopy leaf area. This result was similar to the previous study that investigated the relationship between NDVI and FVC in semiarid grassland (Fan et al., 2009; Tang et al., 2020). Also at the late stage of growth and at the higher ranges of FVC, when the vegetation canopy tends to be closed, NDVI saturates and can no longer be used to detect any differences in FVC (Pontailler et al., 2003). The findings of Lukina et al. (1999) and Sembiring et al. (1998) on estimating vegetation coverage in wheat using digital images and spectral radiance, respectively, were also supported the results in his work.

**Fig. 4.** Coefficient of correlations between GS-NDVI and FVC at a different growing stage. (**: significant at $P \leq 0.01$, ns: non-significant)

**Fig. 5.** NDVI from sensor vs. FVC measured by the visual camera at three growth stages (22, 40, and 52 DAG)

**Conclusion**

The NDVI data acquired using the GS sensor and the visual imaging system were sensitive to changes in plant chlorophyll yield and plant biomass in row crop spinach. Correlations between NDVI and biomass were approximately the same as the correlation of NDVI and chlorophyll yield in the period of growth. Each growing stage demonstrated a different response relationship between sensor response and plant characteristics. At the early and late stages of growth, there were no significant correlations among NDVI with biomass, chlorophyll yield, and FVC. The best growth stage for investigating and estimating the chlorophyll yield and biomass using GS was the period of 28 to 40 DAG, in this period the high values of coefficient of correlation were obtained between NDVI of GS with chlorophyll yield and biomass. To estimate the FVC of spinach, the period of 36 to 40 DAG was considered as a recommended period for
measuring FVC using GS. Results of this study showed that the GreenSeeker has high reliability and capability for the estimation of chlorophyll yield, biomass, and FVC in the middle of the plant growth period.

References
ارزیابی قابلیت حسگر Greenseeker در برآورد وضعیت نیتروژن و تخمین مقدار شاخص FVC

مهران هاشمی جوزانی، حسین پاترپور، جواد حمزه‌ای

چکیده

شاخص پوشش گیاهی سبز کسری (FVC) و شاخص نرمال شده تفاصل پوشش گیاهی (NDVI) از شاخص‌های مهم سبزینگی می‌باشند و ارتباط بسیار قوی با زیستتوده‌های سبز دارند. هدف اصلی این پژوهش، ارزیابی حسگر Greenseeker (GS) در تخمین مقادیر زیستتوده کلروفیل و شاخص FVC در گیاه است. جهت این منظور، از حسگر Greenseeker برای برآورد شاخص‌های ndv و exg استفاده شد. نتایج نشان داد که ارتباط معنی‌دار خوبی بین نرمال شده NDVI و حسگر Greenseeker در مقادیر شاخص FVC وجود دارد. نتایج نشان داد که حسگر Greenseeker در ارزیابی مقدار شاخص FVC بسیار همخوانی دارد. هدف اصلی این پژوهش، ارزیابی حسگر Greenseeker (GS) در تخمین مقادیر زیستتوده کلروفیل و شاخص FVC در گیاه است. جهت این منظور، از حسگر Greenseeker برای برآورد شاخص‌های ndv و exg استفاده شد. نتایج نشان داد که ارتباط معنی‌دار خوبی بین نرمال شده NDVI و حسگر Greenseeker در مقادیر شاخص FVC وجود دارد. نتایج نشان داد که حسگر Greenseeker در ارزیابی مقدار شاخص FVC بسیار همخوانی دارد.

واژه‌های کلیدی: پوشش گیاهی، حسگر نوری، قطعه بندی، کلروفیل

DOI: 10.22067/jam.2021.68387.1013
FORMAT OF MANUSCRIPT PREPARATION FOR JOURNAL OF AGRICULTURAL MACHINERY

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• Title. Concise and informative and not more than 15 words.

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• Corresponding author. Clearly indicate who will handle correspondence at all stages of refereeing and publication, also post-publication. Ensure that phone numbers (with country and area code) are provided in addition to the e-mail address and the complete postal address. Contact details must be kept up to date by the corresponding author.

• Present/permanent address. If an author has moved since the work described in the article was done, or was visiting at the time, a 'Present address' (or 'Permanent address') may be indicated as a footnote to that author's name. The address at which the author actually did the work must be retained as the main, affiliation address. Superscript numerals are used for such footnotes.

Paper configuration

Each paper should have the following distinct sections: Title, Abstract and up to five Keywords, Introduction, Material and methods, Results and discussion, Conclusion, and References. The Acknowledgment (briefly), Recommendations and Nomenclature can also be added. Each section should be prepared as follow:
Abstract: A concise and factual abstract is required. The abstract should state briefly the purpose of the research, the principal results and major conclusions. It should not exceed 250 words. The abstract is presented separately from the article in a single paragraph, so it must be able to stand alone. For this reason, References should be avoided. Also, non-standard or uncommon abbreviations should be avoided, but if essential they must be defined at their first mention in the abstract itself.

Keywords: Up to five keywords appear immediately after the abstract with alphabetical order.

Introduction: Clearly state the research problem and the necessity of research, the objectives of the work and provide an adequate background, avoiding a detailed literature survey or a summary of the results.

Material and methods: Provide sufficient detail to allow the work to be reproduced. Methods already published should be indicated by a reference: only relevant modifications should be described. For the analytical and modeling works a section may be added as “Theory”.

Results and discussion: Results should be clear and concise. The discussion should explore the significance of the results of the work, not repeat them. A combined Results and Discussion section is often appropriate. Avoid extensive citations and discussion of published literature.

Conclusion: The main conclusions of the study is presented in a short Conclusions section, which should be stand alone.

**Paper layout**

The main text should be prepared in A4 paper size, with 1.5 line spacing and all margins of 3 cm. All pages should be numbered sequentially and not more than 15 pages. All lines should be numbered continuously by applying the “Line numbering” command of MS Word.
Fonts

- All writings should be written using Times New Roman font. Both American and British English format are accepted, but not their mixture!
- The font size for title is 14 point and for the main text is 12 point.
- The subtitles should be written in Bold and font size of 12 point.

Units

Please use SI units only. It is not necessary to give the SI unit and (say) its Imperial equivalent. Engineering Notation, where units are in multiples of 1,000, should be used. Thus, we wish to see the use of mm and m and not cm. Use exponent form instead of conventional format (e.g. m s$^{-1}$ and NOT m/s).

Math formulae

Present simple formulae in the line of normal text where possible. In principle, variables are to be presented in italics. Number consecutively any equations that have to be displayed separately from the text in the right margin (if referred to explicitly in the text).

Tables

Number tables consecutively in accordance with their appearance in the text. Place footnotes to tables below the table body and indicate them with superscript lowercase letters. Avoid vertical rules. Be sparing in the use of tables and ensure that the data presented in tables do not duplicate results described elsewhere in the article. The Table caption appears above the Table with font size of 10. Use no border for the Tables.

Figures

Ensure that each illustration has a caption. Supply captions separately, not attached to the figure. A caption should comprise a brief title (not on the figure itself) and a description of the illustration. Keep text in the illustrations themselves to a minimum but explain all symbols and abbreviations used (preferably in the caption). The caption should allow the reader to understand the main elements of what is being shown without needing to refer to the main text. The Figure caption appears below the Figure and written with font size of 10 points. Use no border for the Figures. The font size within the Figure should not smaller than 8 point and bigger than 10 point. Try to present the Figures in gray scale instead of color illustration. The followings are a sample of Table and Figure.
**Table 1** - Consumption of inputs during the first year of saffron cultivation

<table>
<thead>
<tr>
<th>Type of inputs</th>
<th>Consumption (kg ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumed corms</td>
<td>3000</td>
</tr>
<tr>
<td>Urea</td>
<td>100</td>
</tr>
<tr>
<td>Ammonium phosphate</td>
<td>100</td>
</tr>
<tr>
<td>Animal manure</td>
<td>32000</td>
</tr>
<tr>
<td>Consumed irrigation water</td>
<td>3000 (m(^3))^*</td>
</tr>
</tbody>
</table>

* The annual water consumption for saffron cultivation was considered equal to 3000 m\(^3\) (Mahdavi, 1999).

**Fig. 3.** The effects of harvesting time and machine type on the percentage of cracked shells in the outlet

**References**

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