Recycling Pistachio’s Green Hull through Pre-Conditioning by a Screw Press

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ABSTRACT: Different methods have been applied to recycle pistachio’s green hulls, the most important of which are siloing and drying pistachio hulls (using industrial dryers). In both methods, hulls should lose their initial moisture content, which constitutes a considerable portion of their weight. The high moisture content takes more time and energy during the drying process. The initial dewatering of hulls—pretreatment—could greatly contribute to improving the drying process. For this purpose, a prototype of continuous press with a tapered screw design was developed and tested for dewatering pistachio green hulls prior to feeding into a dryer. Results showed that the apparatus dewatered 27% of the hull moisture content. In order to study the effects of screw speed and pistachio variety on the moisture removal, a completely randomized design including three rotational speeds (26.41, 32.52, and 50.24 rpm) and three varieties (Kaleh-ghuchi, Fandoqi, and Ahmad-Aqa’e) was performed in three replications. According to the results, the maximum and minimum moisture removal were obtained in Kaleh-ghuchi (13.13%) and Ahmad-Aqa’e (5.72%) varieties, respectively. Moreover, the minimum and maximum dewatering were observed at speeds of 32.51 and 26.41 rpm, respectively. Economic appraisal showed that the profit gained from marketing this dried hull could be 30 thousands IR per one ton of pistachio. The 40 percent reduction in the drying time of hulls after pressing decreases production costs by 240 thousands IR per each ton of hull.

key word s: Pistachio, Green Pistachio Hull, Dryer, Press.

INTRODUCTION

Based on Iranian statistics, a considerable portion of agriculture produce does not reach the consumer as it goes to waste processing industries which lack the capability to properly and efficiently put every component of a product into good use (Sana, 2010). Once harvested, pistachios are among the products which could not be directly marketed and need certain processes to be prepared. The processes include hulling, unhulled kernel separation, washing, de-watering, blank removal, final unhulled separation, and finally, drying. Therefore, estimates show that, with an annual production of 260 million tons (FAO, 2009), about 400 thousand tons would be the by-products in addition to the removed moisture (Forough-Ameri, 1997). Containing different nutrients, the green hull of pistachio could be used as feed for livestock. Although the storage silos of pistachio residues could be used, they are costly and somewhat impractical due to their limited transferability. Green hulls have high Moisture Content (MC) and the best place and time of drying is at the processing terminals right after hulling (Forough-Ameri, 1997). Industrial drying using indirect heating is another practical and economical method. Moreover, developing such drying equipment for pistachio processing byproduct may prevent the spread of aflatoxin and contamination of pistachio. In order to study how to optimize the drying process of green hulls, a paddle dryer has been developed and tested. The dryer worked at 80°C with a 3.5 tones per 24 hours efficiency (Nava’e and Rasouli, 2009). During the drying process, the residence time of hulls inside the dryer and the proper temperature are highly important for maintaining nutritional values and consumption costs. However, no detailed statistical investigation is available on this topic. In this study, using a dewatering method as a pre-drying process for green hulls and a time...
measurement approach, the required energy and costs for drying of green hulls were studied during their collection and drying stages.

**MATERIALS AND METHODS**

This study was carried out in three phases: 1) developing a dewatering apparatus for pistachio green hulls; 2) evaluating the apparatus; and 3) economic evaluation.

Equipment used for extracting plant juices or oils generally incorporates a screw, a power transmission system, feeding mechanism, housing, and chassis. The present study used the same system and therefore the developed apparatus included:

- A body (including screw housing, an inlet hopper, an outlet and a screen), a screw, end caps, chain drive system, a chassis, and an electromotor.

The following considerations were observed while developing the various components of the press:

- Products are pressed throughout the screw’s length and there is no gap between pieces of the product and the input from the screw to the press component is a uniform mix.
- Pressure increases as screw diameter and pitch are increased and is gradually applied along the screw.

**Apparatus Development**

**Screw**

In similar industries, such as edible oil extraction, the screw is designed to maintain the maximum pressure as depth of the material decreases. The most important part of a press is its screw. The tapered shape of a screw allows for more volume displacement at the inlet than at the outlet, therefore, more pressure is imposed to materials as they move towards the outlet (Sahai and Sing, 1998).

In addition to the variable diameter of the flights along the screw, the proposed press has variable pitch as well. That is, the largest pitch is at the beginning of the screw at the feed inlet, while the shortest pitch is at the outlet end. This property brings about more pressure within a shorter distance.

The following equations were utilized to determine the physical properties of metal sheets used for manufacturing the screw helix (Rakhmjani, 2000):

\[ L = \sqrt{P^2 + (\pi d_0)^2} \]  
\[ l = \sqrt{p^2 + (\pi d_1)^2} \]  
\[ c = \frac{d_o - d_1}{2} \]  
\[ \beta = \frac{360(L - l)}{2\pi c} \]  
\[ \alpha' = 360 - \beta \]  
\[ d_2 = \frac{360 \times L}{\pi \beta} \]  
\[ d_1 = \frac{360 \times l}{\pi \beta} \]

Where,

- \(d_0\) = screw diameter
- \(d_i\) = screw shaft diameter
- \(d_1\) = inner circle diameter of screw planes
- \(d_2\) = outer diameter of screw planes
- \(\alpha'\) = shear angle of screw planes
- \(\beta\) = screw pitch

Each of the above parameters is displayed in Figures (1) and (2):
The screw's shaft and sheets were made of food-grade stainless steel (Figure 3).

**Body**

In view of the tapered (conical) form of the screw, the body was also accordingly turned. The shell thickness was 10mm. The input hopper at the top of the body was installed 10mm from the beginning of the input groove. At the side of the body, a cylindrical sleeve with a 10mm diameter was embedded at the pulp outlet. To remove the juice, holes functioning as a screen were made at the bottom of the body. Figure (4) displays the developed housing from three different views.
End caps for the body were designed based on the location of the shaft’s supports. Ball bearings and thrust roller-bearings were selected.

**Chassis**

In order to develop this chassis, a 60×40mm profile was used. Furthermore, a location for the electromotor was provided on the chassis.
**Electromotor and electric connections**

A 0.55 kW electromotor working at 62.8 rpm was used to operate the device. Availability was the main selection criterion.

To achieve various rotational speeds during performance evaluation tests, a Tele-Mechanic (HBVAC) inverter (made in Turkey) was included. A cutoff switch was placed at the mainspower connection to shut off electrical current when required.

Figure 6. shows a photograph of the device.

![Figure 6. View Of The Constructed Apparatus](image)

**Test**

*Initial moisture content*

Initial green hull moisture content was determined gravimetrically (eq. 8) using a 0.01g prototype Triple Beambalance (MB 2610B) in three replications (Chakraverti, 2005). Moisture percent (w.b.) = (wet matter weight – dry matter weight)/(wet matter weight)  

\[ (8) \]

**Performance evaluation**

Effects of screw speed and pistachio variety on machine performance

The experiment was performed on three pistachio varieties (Kaleh-quchi, Fandoqi, and Ahmad-Aqa’e) at three screw speeds (26.41, 32.51 and 50.24 rpm) in three replications. These speeds were set using an inverter at 20, 30, and 35 percent of the nominals speed. Based on the gear ratio, the rotational speed was calculated for the screw’s shaft using the following equation:

\[ n_1 \times s_1 = n_2 \times s_2 \]  

\[ n_1 = \text{the number of teeth on motor axle gear} \]

\[ n_2 = \text{the number of teeth on screw axle gear} \]

\[ s_1 = \text{rotational speed of motor} \]

\[ s_2 = \text{rotational speed of screw} \]  

Percentage of moisture removed by the press was determined using equation (8) on the wet basis. The effect of screw speed and variety on extracted moisture was analyzed through a factorial experiment in the form of a completely randomized design and one-way ANOVA. Duncan's multiple range test was used for comparison of the means.

**Evaluation of consumed energy**

Three scenarios for collection and transfer of green pistachio hulls were evaluated and compared, in terms of energy consumption:

Scenario 1: collection and transfer of hulling residues outside the terminal.

Scenario 2: drying the material in a convection drier.
Scenario 3: removing the initial moisture using the press and drying the pressed residues in a convection drier.

**Estimating input and output energy**

Energy consumption was evaluated by assessing total energy inputs (as input energy) and time needed to reach the desired moisture content (about 10 to 15 percent) in each of the above methods. The input energies by method are as follows: wet hulls, electricity, pressing device, diesel fuel, drier, and labor, while output energy includes the energy in dried hulls.

**Time measurement**

In order to determine the energy consumption in each method, duration of drying equation was measured, which includes the residence time of green hulls inside the drier. Since there is no relation showing the relationship between hull moisture reduction inside the drier and time, the residence time was used to calculate the capacity-related data of the paddle drier.

**Energy indices used for comparison**

The energy indices were determined using the following equations:

\[ E_R = \frac{E_{\text{out}}}{E_{\text{in}}} \quad (10) \]

\[ \text{NEG} = E_{\text{out}} - E_{\text{in}} \quad (11) \]

\[ E_p = \frac{Y}{E_{\text{in}}} \quad (12) \]

Where,

- \( E_R \) = Energy Ratio
- \( \text{NEG} \) = Net Energy Gain (MJ)
- \( E_p \) = Energy Productivity Index (kg/MJ)
- \( E_{\text{out}} \) = Output Energy (MJ)
- \( E_{\text{in}} \) = Input Energy (MJ)
- \( Y \) = Yield (kg)

The value of consumed input is distributed according to work hours (Mahdavi et al., 2008).

**Economic appraisal**

In this stage, total costs to obtain dried hulls were determined. The cost of consumed inputs included transportation, drier, operator, electricity, diesel fuel (based on working hours during season and consumption per hour). The screw press costs were calculated based on development costs and raw materials used in the fabrication process, bearing in mind the device's life span and working hours per one ton of unprocessed hull.

**RESULTS AND DISCUSSIONS**

The initial MC of hull for different varieties

Table (1) presents the ANOVA for MC of different varieties. As shown, the effect of variety on hull MC is statistically significant at the 1% level of significance.

<table>
<thead>
<tr>
<th>Source of variations</th>
<th>Sum of squares</th>
<th>DOF</th>
<th>Mean squares</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pistachio Variety</td>
<td>0.020</td>
<td>2</td>
<td>0.010**</td>
<td>73.451</td>
<td>0.000</td>
</tr>
<tr>
<td>Error</td>
<td>0.001</td>
<td>6</td>
<td>0.000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ns, * and ** denote non-significant at level of 5% and significant effect at 5% and 1% levels of significance, respectively.

Figure (7) shows the mean values for MC of the three pistachio varieties. According to the figure, the maximum and minimum MCs belong to Fandoghi and Kaleh-ghuchi varieties with 59% and 70%, respectively.
Effects of the independent variables

ANOVA results for the effect of screw speed and pistachio variety on percent moisture extraction are presented in table (2). These results show that the effect of rotational speed and variety on moisture removal is significant at the level of 1%. It is shown that the interaction effect of variety × rotational speed is not significant.

Table 2. Effect of screw’s rotational speed and variety on expelled extract from green hulls

<table>
<thead>
<tr>
<th>Source of variations</th>
<th>Sum of squares</th>
<th>DOF</th>
<th>Mean squares</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Screw Speed</td>
<td>28.323</td>
<td>2</td>
<td>14.161**</td>
<td>31.917</td>
<td>0.000</td>
</tr>
<tr>
<td>Pistachio Variety</td>
<td>295.13</td>
<td>2</td>
<td>147.569**</td>
<td>332.585</td>
<td>0.000</td>
</tr>
<tr>
<td>Speed × variety</td>
<td>2.786</td>
<td>4</td>
<td>0.696</td>
<td>1.570</td>
<td>0.225</td>
</tr>
<tr>
<td>Error</td>
<td>7.987</td>
<td>18</td>
<td>0.444</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ns, * and ** denote non-significant at level of 5% and significant effect at 5% and 1% levels of significance, respectively.

This difference might be due to the effect of different botanical properties of studied varieties on extracted moisture by pressure.

Effect of variety on moisture removal is presented in Figure (8). According to this chart, the minimum extracted moisture belongs to Ahmad-aga’e variety (5.72%), while the maximum is related to Kaleh-ghuchi (13.13%).

Figure (9) shows a comparison of extracted moisture as a function of screw speed. It is shown that the maximum moisture was extracted at 32.51 rpm while the minimum amount was at 23.41 rpm. The efficiency of the apparatus increased as the screw speed was increased from 26.41 to 32.51 rpm. This is mainly because of the fact that any increase in speed would lead to increased pressure which, in turn, increases moisture extraction. As the speed is increased, the pressure also increases. According to the literature, an effective factor in the performance of presses is the screw’s rotational speed. Studies on speed range of 30 to 50 rpm have reported an increased efficiency when speed is increased. (Omobuwajo et al., 1999; Bambgboye and Adejumo, 2007; Eggers et al., 2006; Singh and Bargale, 2000). This confirms the results of this study.
Figure 9. effect of rotational speed on extracted moisture

**Energy consumption**
Energy indices were calculated for each scenario.

<table>
<thead>
<tr>
<th>Table 2. energy indices</th>
<th>Input energy MJ/ton</th>
<th>Output energy MJ/ton</th>
<th>Energy indices E &lt;sub&gt;p&lt;/sub&gt; kg/MJ</th>
<th>Energy indices E &lt;sub&gt;r&lt;/sub&gt; (MJ)</th>
<th>NEG (MJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; Scenario</td>
<td>18501.96</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-18501.96</td>
</tr>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt; Scenario</td>
<td>23100</td>
<td>7400</td>
<td>0.017 &lt;sup&gt;kg&lt;/sup&gt;</td>
<td>0.32</td>
<td>-15700</td>
</tr>
<tr>
<td>3&lt;sup&gt;rd&lt;/sup&gt; Scenario</td>
<td>21000</td>
<td>7400</td>
<td>0.019 &lt;sup&gt;kg&lt;/sup&gt;</td>
<td>0.35</td>
<td>-13600</td>
</tr>
</tbody>
</table>

**Assessing consumption costs**
Costs assessed for the third scenario (using press prior to drying) were 330 thousand IR per one ton of green hull. The predicted profit from this scenario, with regards to the revenue from selling 400 kg of dried hulls, was 270 thousand IR.

Compared to the second scenario, drying hulls after the initial dewatering incurs 240 thousand IR less cost and generates the same profit. Moreover, comparing the productivity index of second and third scenarios, it is slightly increased in the third one. Decreased energy consumption and costs are the results of shorter residence time of the pressed hulls inside the drier than unpressed hulls.

**CONCLUSION**

In pistachio processing operations, hulling is an important post-harvest process. Considering the significant amount of residues from this process and lack of proper technology and practice for processing pistachio green hulls, these residues become wastes with environmental impacts. Therefore, developing a technology and appropriate practice for collection and utilization of these by-products at pistachio processing terminals appears to be necessary. To this effect, a press was developed using a tapered compression screw. Finally, the apparatus was evaluated and the following results were obtained:

The effect of variety on extracted moisture is significant (α = 1%), with the minimum and maximum (twice the former) extracted moisture belonging to Ahmad-aqa‘e and Kaleh-quchi, respectively. Bearing in mind the fact that Ahmad-aqa‘e holds a higher share of production than Kaleh-quchi and Ahmad-aqa‘e, it was more important to evaluate the apparatus’s performance in relation to this variety.

The effect of rotational speed of the screw on moisture removal was significant at level of 1%, while increasing speed from 26.41 rpm to 32.51 rpm enhanced moisture extraction. However, increasing speed to 50.24 rpm reduced moisture removal efficiency.

Drying of dewatered hulls saves 40% in drying time and 240 thousand IR in consumption costs (per ton of hull), and compared to the drying of unpressed hulls, this method is more cost-effective.

Removing moisture pistachio’s green hulls prior to drying, as a pre-processing practice, is essential for accelerated handling of these residues and reduction of their environmental impact, despite the related start-up cost of equipment.

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