Investigation into the Effects of Impeller Vane Patterns and Pistachio Nut Size on Hulling Efficiency of Pistachio Nuts using A Centrifugal Huller

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Abstract
The aim of this study was to investigate the effect of machine parameters on hulling performance of pistachio nuts using a centrifugal huller. Two independent variables including impeller design (material and configuration) of centrifugal huller and size of pistachio nut were selected for evaluating of the machine in a factorial design based on completely randomized block. The overall performance was expressed in terms of hulling efficiency and breakage percent. Forward-curved impeller vanes made of aluminum gave highest hulling efficiency (92.77%) than that with mild steel or rubber vanes. Large size pistachio nut (length > 16 mm) at 10.5% (d.b.) showed the higher hulling efficiency (93.37%) using forward curved aluminum vane. However, the breakage percent was found to be minimum (8.2%) with the medium pistachio size having average length between 14 and 16 mm.

Keywords: Pistachio nut; Centrifugal hulling; Hulling efficiency; Breakage percent

Introduction
Pistachio is cultivated in Middle East, United states and Mediterranean countries. Pistachio nut is one of the major agricultural products produced in Iran, mainly in Rafsanjan, Kerman and south Khurasan provinces. It has been reported that Iran has produced about 275,000 Mt of pistachio nut in 2003, which is approximately 54.7% of the world’s pistachio production, and exported approximately 184,946 tones of nut to different countries, a value about 679.94 million dollars profit [1]. Thus, one of the most non-petroleum valuable products of Iran exports is annually the pistachio nut that has great impact on its economic. Pistachio kernels are a good source of fat (50–60%) and contain unsaturated fatty acids (linoleic, linolenic and oleic acids), essential for human diet [2,3]. It is consumed in confectionery and snack foods. The shell (endocarp) of pistachio nuts split along their sutures which is a desirable trait because pistachio nuts are usually marketed in-shell for eating out of hand as a snack food. Because of the deep green color of pistachio kernels, it is favored in the ice cream and pastry industries [4].

When pistachios arrive at the processing plant, the following procedures are conducted: (a) huling, to separate the soft hull from nuts; (b) trash and blank separation, to remove blank pistachios and trash such as small branches, remaining shells and leaves; (c) unhulled pistachios separation, to remove unhulled and unripe nuts; (d) washing, which involves spraying water at high pressures on the pistachios to clean the nuts; (e) drying, to decrease moisture content of pistachios from 37–40% to the appropriate level; (f) split nuts separation, to separate split nuts from non-split ones; (g) salting; (h) roasting; and (i) packaging [5]. In production process of pistachio, huling is the most important process after harvest [6-9]. In Iran, huling of pistachio is different according to softness or hardness of it. Those which have soft skin are hulled by bolt type huling machine and pistachio with hard skin are hulled by another machine that name unriper hule.

Bolt type huling machine is the only commercial mechanized method in Iran. The machine has been developed and improved during the last 50 years. The main part of the machine is a rotating drum covered by the heads of M6 bolts. The soft skin is detached by vertical and shear stresses produced by these bolts against a fixed blade. This machine are made and designed in local workshops without any attention to mechanical properties of pistachio and many of its parameters determined experimentally [6,7]. In addition, bolt type huling machine pistachio only hul pistachio and the subsequent processes, including washing and dehydrating is fulfilled by a long time delay, causing Aflatoxin disease [10]. Hence, a centrifugal pistachio huling machine was designed and manufactured by authors that can do huling, washing and dehydrating processes simultaneously. As part of the machine development efforts, present study is aimed to investigate the effect impeller design (material and configuration) of centrifugal huler and size of pistachio nut so as to obtain maximum hulling efficiency and minimum breakage percent.

Materials and Methods
Preparation of raw material
The O’hadi (or Fandoghi) is one of the major commercial varieties, which was selected for this research work. This cultivar was obtained from Rafsanjan city, Kerman province in Iran during 2007 year. A portion of pistachios equal to eighty kilograms was transported to laboratory. The samples were cleaned to remove all foreign matters as well as broken nuts. From this pile, at random samples of pistachio nuts were drawn for experiment. This methodology was used to ensure the uniform sample size [11]. To study the effect of sample’s sizes in hulling efficiency and breakage percent, the samples of studied variety were graded into three size categories (small, medium and large) using 14 and 16 mesh sieves.

Experimental set-up
Experimental set-up for huling of pistachio nut as shown in Figure

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is developed at Department of Agricultural Machinery Engineering, Ferdowsi University of Mashhad, Mashhad (Iran). Modeling and mechanical analysis of machine is performed using solidworks 2007 software and cosmos 2007 software, respectively.

Hulling unit and power transmission

In order to hull pistachio in this machine, centrifugal force is used. The unit consists of two main parts: the hulling set and the power transmission system. The hulling set consists of a rotating drum and a separate rotating circular base – plate with an impeller that mounted on a central shaft. These parts rotate in opposite directions, employing two separate electrical motors. The power transmission system of machine is mechanically by belt and pulley, so that they convey power of 3 hp between electrical motors and hulling set.

Impeller vanes

To study the effects of material of construction and shape of impeller vanes on hulling performance, large size pistachio nut (moisture content 10.5% db; length > 16 mm) was used with the peripheral speed of 50 m/s respectively. The impeller vanes were made of three different materials, namely aluminum, mild steel and rubber and each having three different shapes, namely straight, forward-curved and backward-curved (Figure 2).

![Figure 1: The experimental set-up for hulling of pistachio nut.](image1)

![Figure 2: Different impeller designs. (a) Straight vane; (b) Forward curved vanes; (c) Backward curved vanes.](image2)

| Variation source | Degrees of freedom | $F_{critical}$ | $F_{calculated}$ |
|------------------|--------------------|---------------|-----------------|
| Replication      | 3                  | 3.39**        | 0.89**          |
| Material         | 2                  | 530.13**      | 89.64**         |
| Vane shape       | 2                  | 1321.50**     | 53.97**         |
| Material × vane shape | 4              | 48.27**       | 63.57**         |

**Significance at 1% level

Table 1: Analysis of the variance showing the effect of material of construction and shape of vane on hulling performance.

Pistachio nut size

Three size fractions of pistachio nut (m.c. 10.5% db), namely large, medium and small were taken with similar peripheral speed as earlier.

Procedure

To conduct a performance evaluation, the hopper (rotating drum) was filled with the pile of pistachio nuts at specified moisture content and the total number of nuts ($N_t$) was determined by counting. Then, the power supply was switched on to run the electric motors and set the working components of the huller in motion. The number of pistachio nuts that were completely hullud and unbroken ($N_c$), completely hulled but broken ($N_b$) and partially hulled and broken ($N_n$) were determined at the end of each run. The performance of the huller was evaluated on the basis of the following indices:

1- Hulling efficiency ($E_h$) in percent is defined as the ratio of the mass of the hulled material to that of the feed, and is expressed as [12],

$$E_h = \frac{(N_c + N_b) \times 100}{N_t}$$

2- Breakage percent ($E_b$) is expressed as [12],

$$E_b = \frac{(N_b + N_n) \times 100}{N_t}$$

In order to modify the speed of the rotating circular base – plate during the tests, an inverter with an accuracy 0.01 m/s was used.

Statistical analysis

The experiments were conducted at least in four replications for each impeller vanes and pistachio size then the average values reported. Non-linear relationship among hulling efficiency and breakage percent to impeller vanes and pistachio size were obtained using regression analysis (Microsoft Excel software 2003). The analysis of variance (ANOVA) was carried out on completely randomized block design with factorial experiment using SPSS16 software. The F test was used to determine significant effects of each treatment.

Results and Discussion

Analysis of variance

The results of variance analysis which was carried out to examine the effect of treatments (studied effective factors) on hulling efficiency
Effect of material and shape of impeller vanes

Figure 3 and Figure 4 show that irrespective of the shape of vane, the hulling efficiency with aluminum vanes was slightly higher than that with mild steel or rubber vanes. The higher hulling efficiency with aluminum vanes may be attributed to the less friction (having lower coefficient of dynamic friction) offered by the vane to the pistachio nut moving along it and thereby impacting the pistachio nut against a stationary surface with high impact force thus resulting in more hulling. Joshi (1993) also obtained higher hulling efficiency for pumpkin seed when aluminum vanes were used for the impeller. Irrespective of the material of construction, forward-curved shape impeller vanes resulted higher hulling efficiency in comparison with backward-curved and straight shaped vanes. The difference in hulling efficiency might be due to the possible influence of vane shape on the pistachio discharge velocity both in magnitude and in direction [13]. With forward curved vane, the pistachio discharge angle would be smaller and, therefore, higher shearing could be expected, resulting in greater removal of the hull. For any shape of vane, the breakage percent going along with hull was slightly more with aluminum vanes compared with either mild steel or rubber vanes. As stated earlier, with the aluminum vanes, impacting of pistachio against a stationary surface with high impact force might have contributed to more brokens consequently more breakage percent. More breakage percent with straight vanes than other shape might be attributed to high discharge velocity of the pistachio with a larger discharge angle, resulting their re-bounce on the impeller and fragmentation further.

Effect of size of pistachio nut on hulling performance

Figure 5 show the effect of pistachio nut size on hulling performance using impeller fitted with forward-curved aluminum vanes. It was observed that hulling efficiency increased as the size of the pistachio nut increased, which is attributed to the larger magnitude centrifugal impact on the pistachio nuts. However, the breakage percent was found to be minimum for medium size. The hulling of small seeds (length < 14 mm) showed considerable increase in breakage percent.

Conclusions

Hulling is the most important process after harvest in pistachio production. In Iran, pistachio hulled by bolt type hulling machine and the subsequent processes, including washing and dehydrating is fulfilled by other machines. These machines made without considering mechanical properties of pistachio that this causes to break considerable percentage of pistachio when hulling, so it seems necessary to have a machine with high efficiency to hull. A mechanical hulling process based on centrifugal impaction method could be successfully used for separation of kernel and hull fraction of pistachio nuts. Forward-curved aluminium impeller vanes might be used for highest hulling efficiency in comparison with backward-curved and material of construction, forward-curved shape impeller vanes resulted higher hulling efficiency with 8.22% breakage percent; the latter value could be as low as (6.42%) with similar impeller vanes made of mild steel or rubber vanes. The higher hulling efficiency with aluminum vanes was slightly higher than that with mild steel or rubber vanes. The higher hulling efficiency with aluminum vanes may be attributed to the less friction (having lower coefficient of dynamic friction) offered by the vane to the pistachio nut moving along it and thereby impacting the pistachio nut against a stationary surface with high impact force thus resulting in more huling. Joshi (1993) also obtained higher hulling efficiency for pumpkin seed when aluminum vanes were used for the impeller. Irrespective of the material of construction, forward-curved shape impeller vanes resulted higher hulling efficiency in comparison with backward-curved and straight shaped vanes. The difference in hulling efficiency might be due to the possible influence of vane shape on the pistachio discharge velocity both in magnitude and in direction [13]. With forward curved vane, the pistachio discharge angle would be smaller and, therefore, higher shearing could be expected, resulting in greater removal of the hull. For any shape of vane, the breakage percent going along with hull was slightly more with aluminum vanes compared with either mild steel or rubber vanes. As stated earlier, with the aluminum vanes, impacting of pistachio against a stationary surface with high impact force might have contributed to more brokens consequently more breakage percent. More breakage percent with straight vanes than other shape might be attributed to high discharge velocity of the pistachio with a larger discharge angle, resulting their re-bounce on the impeller and fragmentation further.

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