# Separation of shelled walnut particles using pneumatic method

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**Abstract:** Separation of shelled walnut particles was studied on two varieties of Persian walnut, Poost-Kaghazi and Poost-Sangi using pneumatic method. The moisture contents of the samples were determined. The particles were considered in three categories of shell, kernel and shell-kernel together. Each category was manually classified based on their size, in three portions of 1/8, 1/4, and 1/2, as well as the whole kernel and whole walnut. The terminal velocity of each group was determined. The shelled walnuts were sieved and classified in three groups of small, medium and large. The effects of separation time (5, 10 and 15 seconds), feeding value (50 to 80 gr) and air velocity on separation of the kernels and shells were studied for both varieties. The interaction effects were also studied for three walnut sizes (small, medium and large). The terminal velocity was the highest for the whole walnut and the whole kernel while it was lowest for 1/4 and 1/8 of the shell. The best separation was performed at air velocities of 9.20, 10.04 and 10.94 m/s with 98.2%, 98.9% and 98.2%, respectively.

**Keywords:** Pneumatic, separation of kernel and shell, terminal velocity, walnut, postharvest, shelled walnut, Persian walnut

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## 1 Introduction

Walnut fruit (*Juglans regia* L.) originates from Central Asia. On a global basis, walnuts rank the second behind almonds in nut production. China, the United States and Iran are the major producers, with about 25%, 20% and 11% of total global production, respectively[1]. Unfortunately, despite having 11% of world production, Iran only owns less than 1% of international export[2]. Walnuts are usually available in markets as shelled or in-shell after drying. This nut is an excellent source of omega-3 and omega-6 fatty acids, melatonin and several antioxidants[3]. It contains approximately 60% lipids and 54% unsaturated fatty acids[4].

A perplexing problem faced in commercial production of nuts and similar products is the separation of the shells and husks from the meat. Hand cracking of the nutshell and separation of the meat was traditional and remains the most efficient means in terms of separating the nutmeat. The nutmeat represents about 42% to 44% of the total weight of the nut, from the nutshell for English walnuts. However, for large scale producers, hand cracking and separation is not suitable from the standpoint of time and cost of labor[5]. The manual inspection is very time consuming and labor intensive because the shell and meat fragments are very similar in size and color. An accurate automated inspection method would allow processors to save on labor costs while at the same time ensuring product quality[6].

Physical and aerodynamic properties of agricultural products are essential engineering data for designing and developing postharvest handling and processing operations[7]. The properties of each product, even each variety of a product, could be different. Knowledge

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about those parameters, which are necessary for the design, could help to reach a specific and accurate purpose. Knowledge about morphology and size distribution of walnuts and kernels is also essential for an accurate design of equipments for cleaning, grading and separation of the shelled walnuts[8]. Those systems and methods which have already been tested for separation of walnut shell and kernel (meat) are machine vision[6], hyperspectral fluorescence imaging[9], magnetic method[5,10], and floatation in water[11].

The fluidized bed separator, also known as the gravity separator or air table, makes a highly sensitive dry separation on the basis of one of the three particle characteristics of density, size or shape. When two of these characteristics are controlled within certain limits, the fluidized bed separator is unmatched in its ability to separate a complex mixture into a continuous gradation across the range of the differentiating characteristic (light to heavy, fine to coarse, or play to granular), while permitting the isolation of many intermediate fractions between the two extremes[12].

Aerodynamic information of shelled walnut particles is important for developing separation equipment in postharvest processing of walnut. It has been reported that physical and aerodynamic properties of grains and seeds are used for designing various types of cleaning, separating, sorting and conveying equipments[13]. Not much information is available about the properties of Persian walnuts which are necessary for the separation of the particles of shelled walnut.

The objective of this study was to determine the properties of different parts of two varieties of Persian walnut, and to evaluate the influence of some effective parameters on terminal velocity in order to apply the results for the design of equipments for separation of different particles of the shelled walnuts.

## 2 Materials and methods

In this research, two Persian walnut varieties of Poost-Kaghazi and Poost-Sangi, cultivated in Iran, were studied. The samples were purchased from the local markets in Tehran and Damavand, Iran. The samples were stored in fridge at 4℃ for experiments. The walnuts were shelled using a walnut-sheller developed and constructed in the Department of Agrotechnology, College of Abouraihan, University of Tehran[14]. Then the shelled walnuts were manually sieved and categorized based on the particle size by using standard mesh screens. The "whole walnut" was also used for experiments. In this article, the whole walnut means the complete non-dehulled walnut and the shell-kernel means a piece of shelled walnut which consists of both shell and kernel together.

For determination of the moisture content, an amount of 15 g of each particle (shell, kernel (meat) and shell-kernel) were dried in an air oven at 130℃ for 24 hrs in three replications. The moisture content was calculated according to ASAE standard[15] based on the initial and the final sample weights using Equation (1):

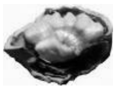
$$MC_{w.b.}, \% = \frac{W_i - W_d}{W_i} \times 100 \qquad (1)$$

where, $MC_{w.b.}$ is moisture content on wet basis; $W_i$ is the initial weight and $W_d$ is the weight of dried materials or final weight.

The whole walnut and the individual particles of the shelled walnuts (Table 1) were considered in this research in order to determine the terminal velocity of each particle. The pieces of the shelled walnuts were then classified based on the size, by using standard sieves, in three groups of small (x < 7 mm), medium (7 < x < 12.5 mm) and large (x > 19 mm) sizes and each group was studied separately.

The terminal velocity was measured using a cylindrical cylindrical air column in which single pieces or an amount of shelled walnut particles of each classification in Table 1 were suspended (Figure 1). The column was made of transparent plastic and had a 60 cm height and 14 cm diameter. A centrifugal fan produced a vertical flow of air upward in the column up to air velocity of 40 m/s. The airflow was distributed uniformly in the column by the use of mesh screens and parallel tubes at point A. The cross section of the column including tubes is shown in Figure 1. The grid, which was used as the base or tray for the samples, also straightened the airflow and reduced turbulence. The air velocity was controlled by an inverter speed regulator. For each test, certain amount of shelled walnuts (feeding value) was placed on a perforated screen set at the bottom of the column (point B). The airflow was blown though the samples while the air velocity was increasing by using the inverter. Terminal velocity was considered to be the velocity at which the sample was just lifted off the screen. The air velocity was measured with a digital anemometer (Lutron AM-4206, Taiwan) with a 0.1 m/s sensitivity[7,16,17]. Five replicate measurements were taken for each sample treatment.

**Table 1 The different particles sizes of shelled walnut**

| Explanation | Pictures |
|---|---|
| Whole walnut |  |
| One-half walnut |  |
| One-quarter walnut |  |
| Whole kernel |  |
| One-half kernel |  |
| One-quarter kernel |  |
| One-eight kernel |  |
| One-half shell |  |
| One-quarter shell |  |
| One-eight shell |  |

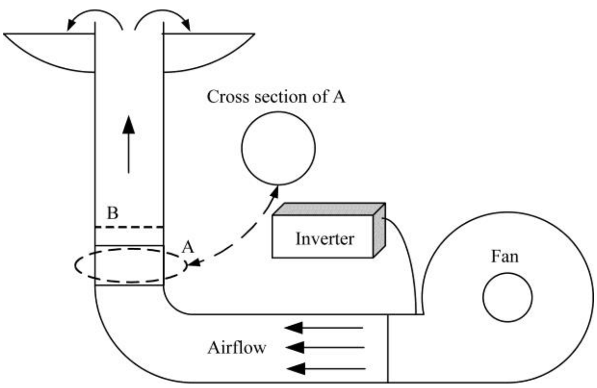



Figure 1 A schematic diagram of the terminal velocity analyzer

Firstly, the terminal velocity was separately determined for different samples sizes of the shell, kernel, and the shell-kernel of both varieties (Poost-Kaghazi and Poost-Sangi), and then separation tests were conducted for four feeding weights values (50, 60, 70 and 80 g) of each particle size and a range of air velocities. The airflow was blown though the samples while the air velocity was increasing. For each running test, the time was set to zero when the particles started to move upward in the column. The weight of the particles which moved out of the column was measured after 5, 10 and 15 seconds. The set time was related to the density, size, and shape of different parts of walnut. So the range of the air velocity for each group varied based on the set time. Then the individual and interaction effects of the parameters on the terminal velocity were studied.

A completely randomized experimental design was used along with factorial arrangement of treatments. The individual and interaction effects were determined using SAS software. The statistical parameters such as $R^2$ and *RMSE* were considered for comparison purposes.

## 3 Results and discussion

The levels of moisture content of different parts of the samples are presented in Table 2. The moisture content of the shell was higher than that of the kernel for both varieties. Similar moisture content levels have been already reported for the shell, kernel, and whole walnut[18].

**Table 2 The moisture content of the samples for two Persian walnut varieties of Poost-Sangi and Poost-Kaghazi**

| Sample | Moisture content (%, w.b.) | |
|---|---|---|
| | Poost-Sangi | Poost-Kaghazi |
| Whole walnut | 5.63 | 5.21 |
| Shell | 7.13 | 6.31 |
| Kernel | 2.70 | 2.66 |
| Shell-kernel | 4.98 | 4.23 |

Terminal velocity and fluidization of each particle are related to the size density and the shape of the particles[19]. The required air velocity for fluidization of each particle varies with the variation of the density, size, and shape of different parts of walnut. The terminal velocities of different particles of shelled walnut are shown in Table 3.

The values are the average of at least five measurements. The terminal velocity of the whole walnut was 14.12 m/s for Poost-Sangi and 12.32 m/s for Poost-Kaghazi. These values are within the range of the results in the previous research[20] but in a lower range compared to the research by Khir et al[7]. This is probably due to the difference in moisture content of the samples. The results are comparable considering the differences in moisture content levels. The one-eight shell and one-half walnut particles exhibited the lowest and the highest values for both varieties, respectively. The particles with similar terminal velocity values (Table 3) could be classified in the same group and then apply the relevant air velocity in order to separate different parts of each group. The terminal velocities of the kernel particles of Poost-Kaghazi were higher than Poost-Sangi; however, the terminal velocities of the shell particles of Poost-Kaghazi variety were lower compared to those of Poost-Sangi variety.

**Table 3 Terminal velocity of different particles for Persian walnut varieties of Poost-Sangi and Poost-Kaghazi**

| Particles | Terminal velocity (m/s) | |
|---|---|---|
| | Poost-Sangi | Poost-Kaghazi |
| Whole walnut | 14.12 | 12.32 |
| One-half walnut | 9.94 | 9.55 |
| One-quarter walnut | 7.54 | 7.65 |
| Whole kernel | 10.30 | 10.92 |
| One-half kernel | 7.86 | 7.94 |
| One-quarter kernel | 7.43 | 7.45 |
| One-eight kernel | 7.69 | 7.86 |
| One-half shell | 7.21 | 6.77 |
| One-quarter shell | 5.16 | 4.79 |
| One-eight shell | 5.15 | 4.49 |

Figure 2 shows the percentage of the separated walnut shells for Poost-Sangi variety in three groups of small, medium and big sizes. The vertical axis shows the percentage of the shells, which are separated after 15 seconds. The single point is presented as the average of five measurements at the given conditions in Figure 2 as well as all subsequent figures. Separation of the shells in the group of small size started at air velocity of about 6 m/s and when the air velocity raised to 9.4 m/s, no shell was remained in the column. The range of required air velocity for separation of medium size was 7.2 to 10.3 m/s while it was 7.8 to 11 m/s for the big size. Similar trend was found for minimum terminal velocities for large, medium and small corn size fraction fiber particles with the values of 2.9, 2.8, 2.5 and 1.6 m/s, respectively[21]. More pressure force is needed to fluidize the material with higher mass density in the constant bed diameter[22]. The terminal velocities among the three groups of small, medium and large sizes were significantly different ($P$ < 0.01). Almost similar results and behaviors were found for Poost-Kaghazi compared to Poost-Sangi variety but the levels were different. In a research, the difference in terminal velocity have been utilized to separate damaged and undamaged grains in a vertical wind tunnel[23].

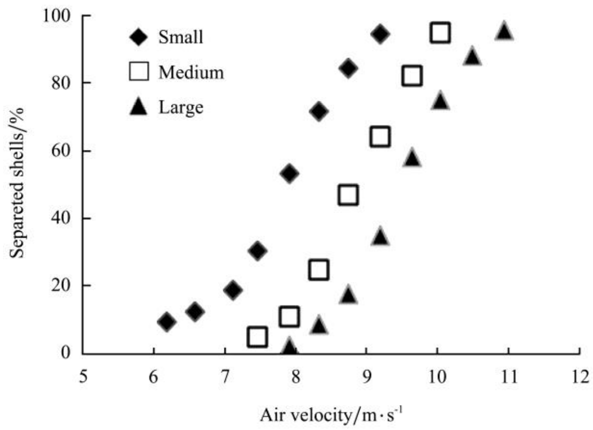



Figure 2 Separation of the walnut shells at different air velocities for three particle sizes of small, medium and large for the variety of Poost-Sangi

Figure 3 shows the separation of the shells of Poost-Sangi variety for different feeding values. At similar air velocities, lower feeding values caused higher percentage of separation. The differences of separation among the given feeding values were found to be significant ($P$ < 0.01). The results for Poost-Kaghazi were somehow similar to Poost-Sangi but the levels were different at each air velocity.

Comparison between the two walnut varieties showed that at certain air velocity, the percentage of the separated shells were always less for Poost-Sangi because of its higher density (Figure 4). Statistically, the differences between varieties were always different for all experimental conditions (particle size, feeding value and air velocity). In most of the experimental conditions, it was possible to separate the shells from the kernels with 100% probability by increasing the air velocity, but in just a few cases about 90% to 95% separation was achieved and increasing of air velocity above certain level caused to have the kernels with shells simultaneously out of the column.

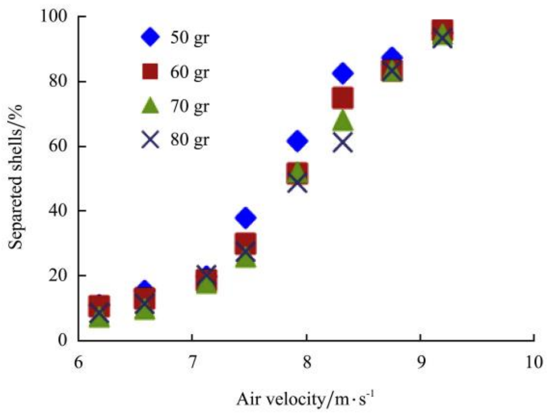



Figure 3 Separation of the walnut shells at different air velocities for four feeding values of 50, 60, 70 and 80 g for the variety of Poost-Sangi

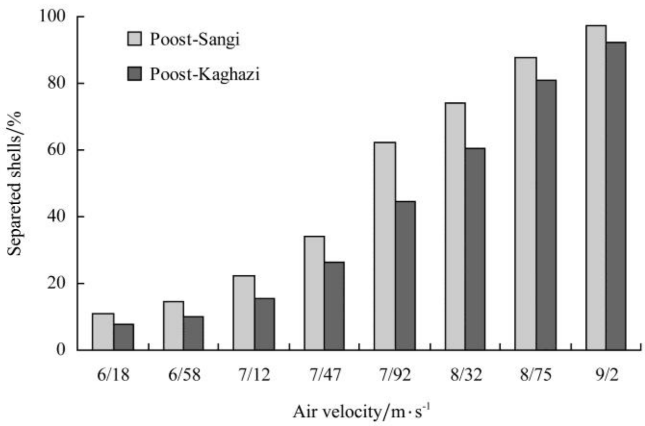



Figure 4 Separation of the walnut shells at different air velocities for two Persian walnut varieties of Poost-sangi and Poost-Kaghazi

The percentage of the separated shells depended on a) variety: because the terminal velocities of the shell and the kernel of both varieties were different; b) amount of the feeding value: more feeding caused more air pressure drop and more resistance for the airflow; c) size of the particle: the terminal velocity is directly related to the size and the shape of the particles[21]; and d) the moisture content of the product: higher moisture content means higher density and higher density causes higher terminal velocity for both shell and kernel of walnut. Similar relation between moisture content and terminal velocity was found for sunflower seeds[24], lentil seeds[25], apricot[26] and pistachio[27], in the previous studies. The increase in terminal velocity with increase in moisture content can be attributed to the increase in mass of an individual sample per unit frontal area presented to the air stream[28]. The other reason is that the drag force is affected by the moisture content of particles[27].

## 4 Conclusions

Based on the results of this research, different terminal velocity values were found for the shell and kernel particles of the two varieties of Persian walnut. However, the terminal velocity increased by increasing of the material density. The differences in levels of terminal velocity for different particles showed that fluidization method is applicable for separation of different particles of shelled walnut if the particles are categorized by sieving. The required air velocity is in the range of 6 m/s to 11 m/s for all particles and each particle needs a range of air velocity in this domain.

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