Design, Fabrication, and Determination of the Optimum Working Conditions of a Peanut (*Arachis hypogaea* L.) Pneumatic Bagging System

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The peanut bagging process is not mechanized, it requires a large amount of human labor. In addition, the shovel or canister used in bagging breaks the peanut shell that causes losses. The purpose of this study is to reduce the required workforce by mechanizing the peanut bagging process, and to determine the optimum working criteria (hose diameter and air velocity) of the prototype machine. A peanut pneumatic bagging machine powered by a tractor power takeoff (PTO) was designed and fabricated to convey peanut pods from the ground and fill the product into the bags. To determine the optimum working conditions of the machine, tests are conducted using three hose diameters (100, 120, and 160 mm) and three air speeds (23, 25, and 27 m s⁻¹). Machine work capacity, fuel consumption, and physical product damage were identified. The terminal velocity value of the peanut pods was calculated as 14.48 ± 2.08 m s⁻¹. Air speed twice the terminal velocity was applied to prevent pressure drop in the transport pipe and ensure flow continuity. The hose with a diameter of 160 mm give the highest work capacity and the lowest fuel consumption. The air velocity of 27 m s⁻¹ in the hose was the most successful in terms of both work capacity and fuel consumption. No product damage was verified during the trials, and the prototype machine was found to be effective for the peanut bagging process.

**Keywords:** peanut, postharvest processes, bagging, prototype machine, working capacity

**INTRODUCTION**

Peanut (*Arachis hypogaea* L.) is a 1-yr warm-climate plant whose fruits grow underground. Producers consider peanut to be more advantageous than other crops due to its high income per unit area (Aşık and Arıoğlu 2018). It has a cultivation area of approximately 31.5 million ha in the tropics and sub-tropics. Peanut is one of the 14 – 15 types of oil crops that make up approximately 90% of the world’s vegetable oil production, with the leading countries in production being China, India, and Nigeria (FAO 2022).

Today, as with many industrial agricultural products (wheat, corn, sunflower, sugar beet, cotton, etc.), there seem to be no issues when it comes to mechanization in the cultivation and harvesting of peanuts—the agricultural production of peanut has been completely mechanized (Uğurluay et al. 2010). However, some of the postharvest operations i.e., drying, bagging, and loading still require an intensive human workforce. After harvest, some soil and stone fragments may be found among the in-shell peanut fruits. This foreign material is removed using mechanical sieves. After sieving and cleaning, the product is usually laid on the edges of fields to be dried to the appropriate moisture level. Here, peanuts are allowed to dry under the sun and to 10% – 11% humidity (wet basis), which is the storage humidity, by mixing several times a day (Fig. 1a). After drying, the product is bagged (Fig. 1b). Peanut growers need human labor for bagging because this process has not yet been mechanized. In the bagging process, workers fill the sacks with peanuts with the help of shovels or tin cans, then sew the mouth part shut and load the sacks onto the vehicles to be transported (Fig. 1c).

The work environment is very dusty and workers are often in forward-leaning positions; this poses occupational health hazards. Workers fill sacks of approximately 60 – 70 kg using muscle power (Fig. 1b).
Moreover, the wages received by the workers are low compared to other laborers; workers consequently do not desire to work in short-term, harsh conditions and without job security.

In addition, during bagging using a shovel or tin, the sharp and hard ends of the working tools break the peanut shell and cause a loss of around 2% (Fig. 1b). This loss is unnecessary and economically challenging for the producer. Also, breakage and damage to the product affect its storage life and quality. These conditions support the need for mechanization in the bagging operation.

Pneumatic conveying systems have been used successfully in a wide variety of conditions for conveying powder and granular materials. In pneumatic systems, the blowing (ventilation) or suction (aspiration) effect of the air flow is used. A fan providing air flow, a power supply, pipes directing the air flow, and various auxiliary parts are used (Deligönül 1986). These systems make it possible to transport materials over distances of hundreds of meters with appropriate equipment selection (Ergür et al. 2005). The speed and flow of the air are important factors affecting the amount of material transported.

In recent years, very limited research has been done on the pneumatic transport and bagging of peanuts. Gao et al. (2020) measured some parameters that occur during the transport of in-shell peanuts with the pneumatic system. They stated that at high air speeds, the capsule damage rate is 5.19% and the transport efficiency is 92.03%. Butts et al. (2018) also conducted a study comparing the pneumatic conveying system and the front loader in loading peanuts from the warehouse to the truck. It is successful in terms of damaged product and foreign matter ratio but only has a work capacity of approximately a third of the front loader.

Direct bagging of dried peanuts on the farm is not mechanized, and a large amount of human labor is needed for bagging. Damages to the peanut pods are also incurred during the process. Hence, the specific objectives of this study were to (1) determine the optimum working parameters (hose diameter and air velocity) that would enable the prototype machine to operate efficiently, and (2) minimize mechanical damage to peanut pods during bagging. Improvements in working conditions using the prototype bagger are addressed in a separate paper.

**MATERIALS AND METHODS**

**Samples Used**

NC-7 in-shell peanut fruits (*Arachis hypogaea* L.) were used as working material for the bagging machine (Fig. 2). Peanut pods were obtained from producers residing in the İmamoğlu district of Adana province, Turkey. Typically, the seeds are large and light pink in color and have an average oil content of 50% (Kadiroğlu et al. 2011). Freshly harvested in-shell peanuts with a moisture content of 22.1% (wet basis) were used for the study. This level of moisture is considered high since moisture content is normally at 11%. Trials were performed at the end of the harvest season (October 2020).

![Fig. 1. a) Drying of shelled peanut fruits on the ground, b) bagging, and c) loading into a vehicle.](image1)

![Fig. 2. NC-7 variety in-shell peanuts.](image2)
**METHODS**

A caliper with an accuracy of 0.05 mm was used to measure the dimensions of the in-shell peanut fruits. Measurements were made on 50 randomly selected peanuts. The basic dimensions of the in-shell peanut fruit are shown in Fig. 3.

**Determination of Some Physical Properties and Terminal Velocity**

Density is one of the important physical properties of agricultural products. Equation 1 was used to calculate the density value of the in-shell peanut.

\[
p_t = \frac{m}{V}
\]

where \(p_t\): grain density, g cm\(^{-3}\); \(m\): grain mass, g; \(V\): grain volume, cm\(^3\).

The individual mass (m) of 50 randomly selected peanut pods was measured using a (Sartorius/GP 3202) precision scale with a readability of 0.01 g. The water displacement method was used to determine the volume of each pod, and the pod density was computed as the ratio of the pod mass to pod volume (Mohsenin 1970). To determine the moisture content of the product, the wet mass values of the fruit samples were recorded. After the weighed samples were kept in the drying oven at 105°C for 24 h, their masses were measured again and the moisture content of the product was calculated according to the wet basis (Mohsenin 1970). In this study, mass and volume measurements of grains were made and only grain density was calculated. The terminal velocity (critical speed) of the product is another value that needs to be determined. Terminal velocity is the maximum velocity an object can reach while falling through a fluid and is critical for developing pneumatic transport methods. Ince et al. (2008) used Equation 2 to calculate the critical velocity of jojoba plant fruits in their study.

\[
V_t = 4\sqrt{P_d}
\]

where \(V_t\): terminal velocity, m s\(^{-1}\); \(P_d\): dynamic pressure of the air, mmWC.

The dynamic pressure value acting on an object in the air stream was calculated using Equation 3.

\[
P_d = 1.3p_c D_e
\]

where \(P_c\): dynamic pressure of the air, mmWC; \(p_c\): grain density, g cm\(^{-3}\); \(D_e\): geometric mean diameter, mm.

The geometric mean diameter value was calculated using Equation 4 (Mohsenin 1970).

\[
D_e = (LWT)^{1/3}
\]

where \(D_e\): geometric mean diameter, mm; \(L\): Length (the length of major axis), mm; \(W\): Width (the length of intermediate axis), mm; \(T\): Thickness (the length of minor axis), mm.

**Design Criteria**

A peanut pneumatic bagging machine prototype was designed using a 3D drawing program (SolidWorks 2016, Dassault Systems SolidWorks Corp.-ABD). The machine transports dried and bulked peanuts in hoses using vacuum (suction) airflow, collects them in a cyclone-shaped tank, and allows the product to be filled into sacks from the bottom of the tank.

During the movements of the peanut pods in the hose, pipe, and cyclone, the highest speeds that will not cause breakage loss were preferred. Appropriate conditions must be created for the product to be transported in the air stream. Different carrying capacities will occur in different hose diameters, and different energy consumption will occur for different carrying capacities. For this study, a spiral polyethylene hose with three different diameters (100, 120, and 160 mm) was used and three different air velocities (23, 25, and 27 m s\(^{-1}\)) were applied. When the cross-sectional area of the hose changes, the air velocity in the delivery channel also changes. To provide the same air speed each time, the fan speed (revolutions per min) must also be changed. The number of revolutions of the pulley that moves the fan and, accordingly, the air flow rate were adjusted by changing the tractor power takeoff (PTO) shaft speed. Air velocity measurements were made with an anemometer (Extech, Model No 407113, USA, measuring range 0.5 – 35.0 m s\(^{-1}\), precision 0.01 m s\(^{-1}\)) from the mouth of the product inlet hose.

The aim was to try to determine the hose diameter and air velocity that could carry the product smoothly with the highest work capacity, lowest energy consumption, and lowest loss amounts. The work capacity (t h\(^{-1}\)) was obtained by measuring the weight of the product bagged after 1 h of operation of the machine. The fuel consumption (liters per t of product transported by the prototype machine, L t\(^{-1}\)) of the tractor engine for different
operating conditions was measured using the ARER brand Fuel Consumption Meter (model 2014, Turkey). Fuel consumption amounts were obtained by connecting the fuel consumption metering device to the fuel system and instantaneously measuring the amount of fuel going to the tractor engine. After each trial, the presence of damages (breaking or splitting in the shell) in the bagged products was checked visually.

The experiments were carried out according to the factorial experiment plan (total of 27 trials) with three repetitions with a total of nine combinations as 3 x 3 (three pipe diameters and three air flow rates). Independent variables were hose diameter and air velocity. Carrying capacity, amount of energy consumed, and mechanical seed damage were investigated as dependent variables. Another aim was to obtain the change in carrying capacity, energy consumption, and mechanical seed damage as a function of hose diameter and air velocity during the transportation of peanuts using the vacuum-type pneumatic transmission system. The statistical analysis was carried out using the SPSS (v. 17.0) package program. The experimental data were subjected to analysis of variance following the factorial experimental design (two factors). Tukey’s HSD test was also performed to obtain the significance between average values.

Machine Design

The aim was to design and develop a vacuum-effect (air-aspirated) pneumatic conveying system which uses aspirated air for the transport and transmission of the in-shell peanuts, but with a simpler structure (Fig. 4). In this system, the fan was placed at the end of the line, behind the cyclone. Thus, a vacuum was created along the entire line, and since the fan was located at the very end of the line, the product could be transported within the system without being damaged. Working with the cyclone principle, the tank separates the product from the air. The cyclone was also used as a tank that collects the product in certain quantities, and the bag filling was done with the help of a discharge cover located under the tank. In this way, intermittent intervals for bagging were made possible, which are necessary to prevent the accumulation of product in the tank.

By taking the product into the system with vacuum air, it was expected that breaking losses would be prevented, extra income would be gained, labor costs would be reduced, and time spent on work would be saved. Previous studies examined the use of cyclone systems to separate heavy materials from light ones in a fluid flow with the help of gravity (Alibaş et al. 1995). There were also some dust and chaff wastes in the heaps of in-shell peanut bulk lying on the ground. The cyclone used at the end of the line also provided a healthier working environment as it separated the dust and chaff in the material from the fan outlet together with the air.

The peanut pneumatic bagging machine was mounted on the tractor and was operated by taking its motion from the tractor PTO (Fig. 5).

The peanut pneumatic bagging machine consisted of the Frame (1), Three-point hitch (2), PTO connection shaft (3), Belt-pulley mechanism (4), Radial fan (5), Fan-tank connection hose (6), Product tank (cyclone) (7), Suction hose for collecting the product (8), Product discharge and bagging mouth (9), Product tank filling level indicators (10), Fan inlet butterfly valve (11) and Product tank air outlet mouth wire mesh (12). The machine worked by taking its movement from the PTO shaft of the tractor.
with the help of a drive shaft (3). The drive shaft was connected to a belt-pulley mechanism (4) in the machine and this mechanism drives a radial fan (5). The suction port of the radial fan (5) was connected to the product tank (7) from the upper part with the connection hose (6) between the fan and the tank. The diameter of the hose (6) between the fan and the tank was 200 mm. In this way, friction losses were tried to be kept at the lowest level. The hose (8) providing the collection of the product was connected to the back of the product tank (7) and its end was free (Fig. 6).

When the radial fan (5) was operated, the air entering the system was discharged through the hose (8) that collects the product, the product tank (7), the connection hose (6) between the fan and the tank, and the fan. If the air intake was fast enough, the in-shell peanut fruits were drawn in from here and carried to the product storage (7). The tank volume was designed for a size that could store approximately three sacks (the average mass of one sack of product was 75 kg). The bulk density of the peanut pods was 245 kg m\(^3\) on average (Akçalı et al. 2006). For this reason, the tank volume was planned to be approximately 1 m\(^3\). The tank works according to the cyclone principle, with cyclonic tanks typically being cylindrical in shape. However, since it was not easy to manufacture a cylindrical-conical tank from sheet metal of this size, a prismatic tank with the same capacity was manufactured. A soft rubber curtain was placed directly opposite the inlet pipe to prevent mechanical damage to the product entering the cyclone. A radial fan with a spiral casing was designed to provide fast and regular air flow. A closed-type impeller was designed and used in the fan.

The velocity of the air entering the product tank (7) significantly dropped due to a sudden increase in the flow section. This sudden decrease in air velocity could not carry the material it brings and releases it in the tank (7). The air entering the tank (7) continued its way with the connection hose (6) between the fan and the tank, and after passing through the fan (5), it was ejected from the fan outlet. In this way, the product was constantly transported into the tank (7) and accumulated.

After the tank was filled to a certain level, the product could be easily bagged by using the sliding gate located at the product bagging opening (9) at the bottom of the tank. To monitor the amount of product accumulated in the tank (7), two product tank fill level windows (10 - 1 and 10 - 2) were placed both on the front (for the tractor driver) and on the side (for the bagging worker). From here, the product level could be continuously monitored and bagging could be done at certain intervals.

In addition, in cases where the air suction of the fan (5) must be cut off quickly, the fan inlet butterfly valve (11) was placed at the suction inlet of the fan (5). The butterfly valve (11) stopped the air flow completely as soon as the guide lever was turned 90° to the right or left.

To prevent the product inside the tank (7) from entering the connection hose (6) on the upper part, a wire mesh (12) was placed. The wire mesh (12) prevented the product from reaching the fan (5) by passing through it and from being damaged by breaking up inside the fan and being thrown out (Fig. 7).

**RESULTS**

The mean and standard deviations of the dimensions of the peanut pods and the geometric mean diameter are shown in Table 1.
The mean and standard deviation values of the mass, volume, and density of the peanut pods are shown in Table 2.

The terminal velocity value of the grain product was calculated and found to be $14.48 \pm 2.08 \text{ m s}^{-1}$. There was a product that was transported in a heap or cluster in the transmission pipe, a pressure drop occurred due to the frictions between the product and the inner walls of the pipe, and a higher velocity air flow was required to ensure the continuity of the transmission. In a similar study, it was reported that the air velocity value to be supplied to the system should be two to three times higher than the terminal velocity value (Akkoç and Arun 1995).

Trials

The bagging capacity and fuel consumption values and changes of the machine is shown in Figs. 8 and 9. The increase in hose diameter resulted in a decrease in fuel consumption and an increase in machine capacity. Likewise, the increase in air speed provided a decrease in fuel consumption and an increase in machine capacity.

Mechanical product damage was not observed in all trials; therefore, product damage was excluded from the statistical analysis. Table 3 shows the results from the variance analysis and Tukey’s HSD test which were conducted to examine the effects of different hose diameters and air velocities on work capacity and fuel consumption.

When the hose diameters were evaluated in terms of work capacity, it was noted that the 160-mm-diameter hose gave the highest work capacity. When the air velocities that occurred in the hoses were evaluated in terms of work capacity, it was found that the air velocity of 27 m s$^{-1}$ gave the highest work capacity. With the use of the prototype machine, the number of workers used for the bagging operation was reduced. The detailed data and the results of the savings in human labor requirements as well as the economic analysis of the bagging work using the prototype machine are presented in Ugurluay and Somay (2022).

The lowest fuel consumption values were obtained using the 160-mm-diameter hose and with the 27 m s$^{-1}$ air speed. The effects of hose diameter and air speed on work capacity and fuel consumption were found to be statistically significant ($p < 0.001$ and $p < 0.01$, respectively). Moreover, the interaction of these two factors was found to be significant only for fuel consumption ($p < 0.01$). A few images of the trials are shown in Fig. 10.

Bagging using the machine eliminated the need to constantly bend over during filling. As the machine aspirated the product, it also prevented the air from being dusty and presented better conditions for the workers.

DISCUSSION

Previous studies on pneumatic transmission have been done on pressure drops, the behavior of the transported
material in the air, dense phase conveying, and automatic control of the transmission system, among others (Pan and Wypych 1997; Wypych and Yi 2002; Güner 2007; Jones and Williams 2008; Hardin 2014). Kılıçkan and Güner (2009) also determined the pneumatic conveying characteristics of chickpeas; in their experiments, the projected area of the chickpea, its terminal velocity, drag coefficient, pressure drop, power consumption, and the mechanical damage and germination test which constitute the seed damage were investigated. A positive low-pressure system was used for the pneumatic delivery of chickpeas. It was found that the power requirement and pressure drop increased with the increase of the blower speed, and that the conveying capacity decreased with the increase in the pipe diameter—contrary to the results in the current study where the conveying capacity decreased with the decrease of the pipe diameter.

In a similar study, Ghafori et al. (2011) investigated the changes in pressure drop, power consumption, and mechanical seed damage in a suction-type pneumatic conveying system of corn and barley seeds. The designed pneumatic conveying system was effective in both aspiration and ventilation. At a 15 t h⁻¹ carrying capacity, it was reported that the air velocity in pneumatic conveying should be reduced below 20 and 15 m s⁻¹ for corn and barley seeds, respectively, to reduce energy consumption and mechanical damage. Butts et al. (2018) compared the pneumatic conveying system with the front loader system in terms of loading peanut pods from the warehouse to a truck and found that the pneumatic conveying system was successful in terms of damaged product and foreign matter rate, but thrice unsuccessful in terms of work capacity.

In measuring some parameters in the conveying of in-shell peanuts with a pneumatic system, Gao et al. (2020) found that increases in fan speed also increase the pod damage rate and transport efficiency, while the increase in the thickness of the cushioning/anti-obstruction layer causes a reduction of these values, where pod damage rate was 5.19% and transport efficiency was 92.03%. The current study reflected similar results considering that the machine was designed completely with aspiration and tried at different air speeds (23, 25, and 27 m s⁻¹), with the highest air speed resulting in the best transport efficiency and with no mechanical damage observed.

Table 3. Results of variance analysis and Tukey’s HSD test.

<table>
<thead>
<tr>
<th></th>
<th>Work Capacity mean ± SE</th>
<th>Fuel Consumption mean ± SE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hose Diameter</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>0.32 ± 0.07b</td>
<td>8.41 ± 0.71c</td>
</tr>
<tr>
<td>120</td>
<td>0.50 ± 0.09b</td>
<td>6.30 ± 0.41b</td>
</tr>
<tr>
<td>160</td>
<td>1.47 ± 0.40a</td>
<td>5.13 ± 0.49b</td>
</tr>
<tr>
<td><strong>Air Speed</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>0.34 ± 0.09b</td>
<td>7.51 ± 1.02b</td>
</tr>
<tr>
<td>25</td>
<td>0.65 ± 0.17ab</td>
<td>6.63 ± 0.49ab</td>
</tr>
<tr>
<td>27</td>
<td>1.30 ± 0.42a</td>
<td>5.70 ± 0.35b</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td>0.76 ± 0.17</td>
<td>6.61 ± 0.41</td>
</tr>
<tr>
<td><strong>HD</strong></td>
<td></td>
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<tr>
<td><strong>AS</strong></td>
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<tr>
<td><strong>HD x AS</strong></td>
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Fig. 10. Views of machine trials, conveying to the tank, and bagging.
CONCLUSION

Design, fabrication, and testing were done for a peanut pneumatic bagging machine prototype which conveys peanut pods from the ground using aspirated air and fills the product into bags to mechanize the sacking process, which is being done entirely using human labor. The 160-mm-diameter hose as well as the air velocity of 27 m s\(^{-1}\) were found to be the most suitable in terms of both work capacity and fuel consumption. Moreover, mechanical pod damage was not observed during the bagging operation, thus preserving peanut pod integrity until processing or consumption. This system can also be used for the bagging operation of similar products with proper settings. The prototype presents innovations in its field and the patenting process of the machine has been initiated.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Yayin/detay/125486/yerfistigi-arachis-hypogaea-Lnda-jips-uygulamasinin-verim-ve-kalite-ozellikleri-uzerine-etkisi. (in Turkish)


