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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Determination of Some Physico-Mechanical Properties and Critical Velocity of Opium Poppy Plant (*Papaver somniferum* L.) 'Ofis 1' (Blue)

Afyon Haşhaşı Bitkisi (*Papaver somniferum* L.) 'Ofis 1'in (Mavi) Bazı Fiziko-Mekanik Özelliklerinin ve Kritik Hızın Belirlenmesi

Orhan GÜNGÖR[1*], İbrahim AKINCI[2]

Abstract

Determination of some physico-mechanical properties of plant products are very important reference studies in terms of design, development and efficient use of tools and machines used in processes such as planting, harvesting, transportation, packaging, storage, product processing, etc. In this study, it was aimed to determine some physico-mechanical properties of the stalk and capsule of Ofis 1 (Blue) poppy plant, which has a significant production size in our country. According to the evaluated research findings, on the basis of average values, poppy capsule height was 37.99 mm, width was 35.82 mm, mass was 5.86 g, volume was 300.73 mm^3, horizontal projection area was 18.66 cm^2, vertical projection area was 17.91 cm^2, critical velocity was 10.22 m s^{-1}, natural angle of repose was 22.8°, and shell ratio was 43.93%. In the study, the poppy stalk was divided into three parts: upper, middle and lower regions. During the harvest period, the wet basis moisture value of the upper region was 7.69%, the moisture value of the middle region was 7.56%, the moisture value of the lower region was 8.03%, and the average moisture value of the poppy stalk was calculated as 7.76%. The average moisture value of poppy capsule at harvest time was determined as 7.69%. The number of plants per unit area in the poppy field was 30.8 pieces m^{-2}, the number of capsules was 55.2 pieces m^{-2} and the capsule/plant ratio was 1.8. Average plant height was 119.7 cm. These values are the data that should be taken into consideration for table height and finger spacing in poppy harvesting machine designs. The majority of the plants per unit area (55.9%) are single capsule. As a result of mechanical tests, poppy stem shear force values were determined between 31.14 N-74.06 N and these values vary according to the thickness of the poppy plant stem. The average compression-crushing forces of poppy capsule were determined as 159.39 N and 110.46 N for vertical and horizontal positions, respectively. As a result of the research, Ofis 1 (Blue) poppy plant physico-mechanical properties and a resource that can be useful for the studies to be carried out in machine design studies for the cultivation and harvesting of poppy plants have been put forward.

Keywords: Opium poppy "Ofis 1" (blue), Physico-mechanical properties, Biological material

[1]***Sorumlu Yazar/Corresponding Author:** Orhan Güngör, Department of Information Technologies, Golhisar Vocational School, Burdur Mehmet Akif Ersoy University, 15030, Burdur, Turkey. E-mail: orhangungor@mehmetakif.edu.tr OrcID: 0000-0002-5398-4571
[2]İbrahim Akıncı, Agricultural Machinery and Technologies Engineering, Faculty of Agriculture, Akdeniz University, 07058, Antalya, Turkey. E-mail: iakinci@akdeniz.edu.tr OrcID: 0000-0002-0057-0930.
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Öz

Bitkisel ürünlerin bazı fiziko-mekanik özelliklerinin belirlenmesi; ekim, hasat, taşıma, paketleme, depolama, ürün işleme vb. süreçlerde kullanılan alet ve makinelerin tasarımı, geliştirilmesi ve verimli kullanılması açısından çok önemli referans çalışmalardır. Bu çalışmada, ülkemizde önemli düzeyde üretim büyüklüğüne sahip olan Ofis 1 (Mavi) haşhaş bitkisinin sapı ve kapsülüne ait bazı fiziko-mekanik özelliklerinin belirlenmesi amaçlanmıştır. Değerlendirilen araştırma bulgularına göre, ortalama değerler bazında, haşhaş kapsülü yüksekliği 37.99 mm, genişliği 35.82 mm, kütlesi 5.86 g, hacmi 300.73 mm^3, yatay iz düşüm alanı 18.66 cm^2, dikey iz düşüm alanı 17.91 cm^2, kritik hızı 10.22 m s^{-1}, doğal yığılma açısı 22.8°, kabuk oranı %43.93 olarak ölçülmüştür. Çalışmada haşhaş sapı üç kısma ayrılmış olup bunlar üst, orta ve alt bölgelerdir. Hasat döneminde üst bölgenin yaş baz nem değeri %7.69, orta bölgenin nem değeri %7.56, alt bölgenin nem değeri %8.03 olarak ölçülmüştür, haşhaş sapının ortalama nem değeri %7.76 olarak hesaplanmıştır. Hasat zamanındaki haşhaş kapsülü ortalama nem değeri %7.69 olarak belirlenmiştir. Haşhaş tarlasında birim alandaki bitki sayısı 30.8 adet m^{-2}, kapsül sayısı 55.2 adet m^{-2} ve kapsül/bitki oranı ise 1.8 değerindedir. Ortalama bitki boyu 119.7 cm'dir. Bu değerler haşhaş hasat makine tasarımlarındaki tabla yüksekliği ve parmak aralıkları için dikkate alınması gereken verilerdir. Birim alandaki bitkilerin büyük bir çoğunluğu (%55.9) tek kapsüllüdür. Mekanik testler sonucu haşhaş sapı kesme kuvveti değerleri 31.14 N-74.06 N arasında belirlenmiş olup bu değerler haşhaş bitkisinin sapının kalınlığına göre değişmektedir. Haşhaş kapsülü ortalama basma-kırma kuvvetleri ise dikey ve yatay pozisyonlar için sırasıyla 159.39 N ve 110.46 N olarak belirlenmiştir. Araştırma sonucunda, Ofis 1 (Mavi) haşhaş bitkisi fiziko-mekanik özellikleri ve haşhaş bitkisinin yetiştirilmesine ve hasat işlemlerine yönelik makine tasarım çalışmalarında yapılacak çalışmalara yararlı olabilecek bir kaynak ortaya konmuştur.

Anahtar Kelimeler: Ofis 1 (Mavi) haşhaş, Fiziko-mekanik özellikler, Biyolojik malzeme

1. Introduction

Determination of some physico-mechanical properties of plant products are very important reference studies in terms of design, development and efficient use of tools and machines used in processes such as planting, harvesting, transportation, packaging, storage, product processing, etc.

In Turkey, the traditionally cultivated poppy plant (*Papaver somniferum* L.) belongs to the *Papaveraceae* family. It is an annual crop. Alkaloids are obtained from the capsules of the poppy plant, and poppy oil is extracted from its seeds (Arslan et al., 2008; Seçmen et al., 2000; Erol and Yanık, 2019). Poppy has been cultivated in Anatolia since around 2000 B.C. The plant was freely produced in Turkey in 1933, following the declaration of the Republic. However, between 1971 and 1974, poppy production was banned, and starting from 1987, the Turkish Grain Board (Toprak Mahsulleri Ofisi - TMO) was tasked with overseeing poppy cultivation (Hacıyusufoğlu, 2013). Globally, poppy is grown on 87,642 hectares, with Turkey accounting for 56,511 hectares (64%). With this figure, Turkey holds the first place in global poppy production (TMO, 2019). In Turkey, varieties such as Ofis 2 (white), Ofis 1 (blue), Ofis 4 (yellow), and others are cultivated (TMO, 2021). Accordingly, the most cultivated poppy varieties in Turkey are white (69%), blue (17%), and yellow (14%) seeded varieties. Poppy seeds can be of various colors, including blue, yellow, pink, white, and brown. Poppy is better cultivated in areas with moderately warm summers and sufficient rainfall. Poppy seeds germinate at +4 °C when there is enough moisture in the soil. The poppy plant has a total temperature requirement of 2300-2700 °C and an annual precipitation requirement of 600-700 mm during its growth period (TMO, 2017). The second most produced poppy variety in Turkey is blue, developed by the Turkish Grain Board on April 19, 2016.

Figure 1 illustrates the developmental stages and vegetative parts of the blue poppy. The developmental process includes leafing, budding, flowering, capsule formation, and maturation phases. The vegetative cycle of the poppy plant lasts approximately 110-280 days. During this period after planting, activities such as hoeing/thinning, irrigation, fertilization, pest control, and harvesting are carried out (İşler, 2024). The vegetative components of the poppy plant consist of a main stem (stalk), leaves, lateral branches formed on this main stem, and poppy capsules developing on each lateral branch. There is a node point between the capsule and the stalk.

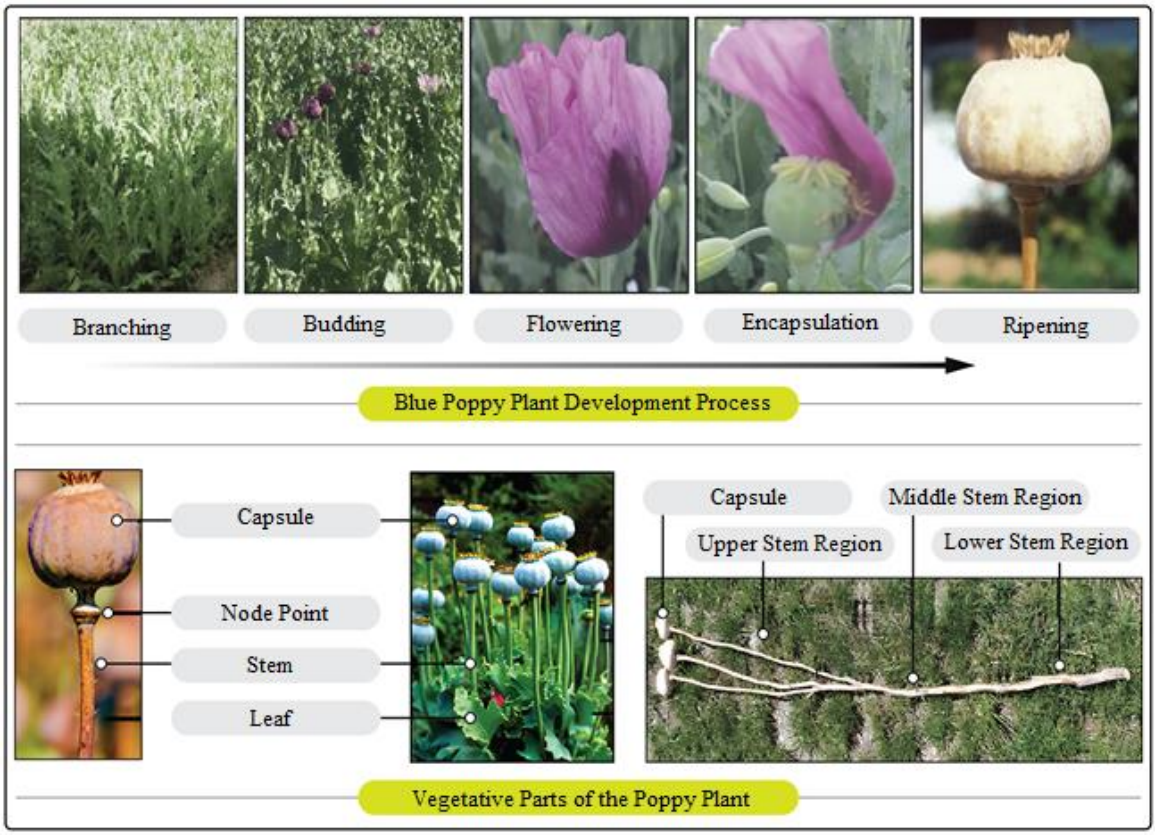

Figure 1. Developmental stages and vegetative parts of the blue poppy plant

Vegetable products are harvested once they reach a specific maturity period. For medicinal and aromatic plants, the optimal harvest period is when the moisture content is between 7-12% (Baydar, 2009). When the poppy plant reaches harvest maturity, the capsules are harvested manually by breaking the capsules at the knot point. In mechanical harvesting, it is recommended to harvest by cutting at most 10-20 cm below this knot point (Hacıyusufoğlu, 2013). This height is important for the table height of the harvester. Determination of product dimensions (width, length, mass, volume, footprint area, critical velocity, natural stacking angle, etc.) and geometric properties of agricultural products are of great importance in the design of units such as sorting, harvesting, collecting, threshing, cleaning, transferring, storing, etc., especially in harvesting machines. In addition, knowledge of these properties also contributes to the design of vehicles used for processing, drying, storage and transportation of plant products (Özarslan, 2002; Dash et al., 2008; Özlü and Güner, 2016; Polyák and Csizmazia, 2016; Taşova and Dursun, 2023). In addition, knowing the fracture resistance of plants and fruits plays an important role in harvesting machine designs (Kocabıyık et al., 2009).

The aim of this study was to determine some physico-mechanical properties of Ofis 1(blue) poppy plant, the second most produced poppy variety in Turkey. To achieve this goal, the research encompasses the determination of product dimensions, geometric characteristics, moisture content, plant and capsule numbers/ratios per unit area, stem cutting force, and capsule rupture resistance/force values.

2. Materials and Methods

In the experiments, the plant material used was Ofis 1 poppy variety, developed by TMO in 2016. All dimensional measurements and mechanical tests conducted in the study were carried out using measurement methods outlined in relevant literature.

Poppy capsule dimensions were measured using a digital caliper with a precision of 0.1 mm. Mass measurements of the capsules were conducted on a digital scale with a precision of 0.01 g. The shell ratio was calculated by dividing the mass of the capsule shell by the mass of the entire capsule. Volume measurements of the capsules were determined by immersing the capsules, taken from the stem, into a container filled with toluene, and the displaced liquid volume was calculated accordingly (Kara, 2012). The horizontal and vertical projection areas of the poppy capsules were determined using image analysis. Photographs taken with a digital camera from a fixed height were analyzed using an image processing program to calculate the area of the image (Kara, 2012). The critical velocity was determined using the aspiration method, where the air velocity at which the capsules remained stationary/suspended was defined as the critical velocity. Airflow measurements were made with an anemometer with a precision of 0.1 m s^{-2}. The tunnel using the aspiration method is 10 cm in diameter, an adjustable velocity airflow system is installed. The natural repose angle was determined by pouring poppy capsules from a fixed point onto a flat surface, and the angle formed by the lateral surface of the resulting pile with the horizontal was measured as the natural repose angle (Kara, 2012). Measurements for certain physico-mechanical properties of the poppy capsules were repeated five times. The moisture content values for both the poppy capsules and stems were determined using the oven drying method. Measurements were carried out on five samples. First, the fresh weights of the capsule and stem samples were measured as shown in Equation 1. Then, these samples were placed in a drying oven at 105 °C for 24 hours and their dry weights were measured to determine the percent moisture content on a wet basis (Mohsenin, 1986).

$$Moisture_{w.b.} = \frac{A-B}{A}.100 \quad \textbf{(}\text{Eq. 1)}$$

Moisture w.b.: Moisture content (%)

A : Wet sample weight (g)

B : Dry sample weight (g)

In the stem cutting and capsule compression/crushing tests, moisture values in the range of 7-12% at harvest were taken into consideration (Baydar, 2009).

"Unit Area Method" was employed to determine the plant count, capsule count, plant heights, and capsule numbers on each plant. A unit area of 1 m^2 was selected for this purpose, and the locations of unit areas in the poppy field were randomly chosen. The experiments were conducted with five replications. In the trials, the plant

and capsule numbers in each unit area were determined, plant heights were measured, and the number of capsules on each plant was identified. For the determination of poppy stem cutting force values, three regions on the plant stem were considered: namely the lower region, middle region, and upper region. Cutting trials were performed in these regions. For the determination of poppy capsule compression/breaking force values, vertical and horizontal compression/breaking measurements were conducted. TST Mares brand universal mechanical testing equipment at the Agricultural Machinery and Technologies Engineering laboratory of Akdeniz University, Faculty of Agriculture, was used for measurements. The experiments were carried out with five replications. Relevant visual examples of the measurements and mechanical tests are provided in *Figure 2*.

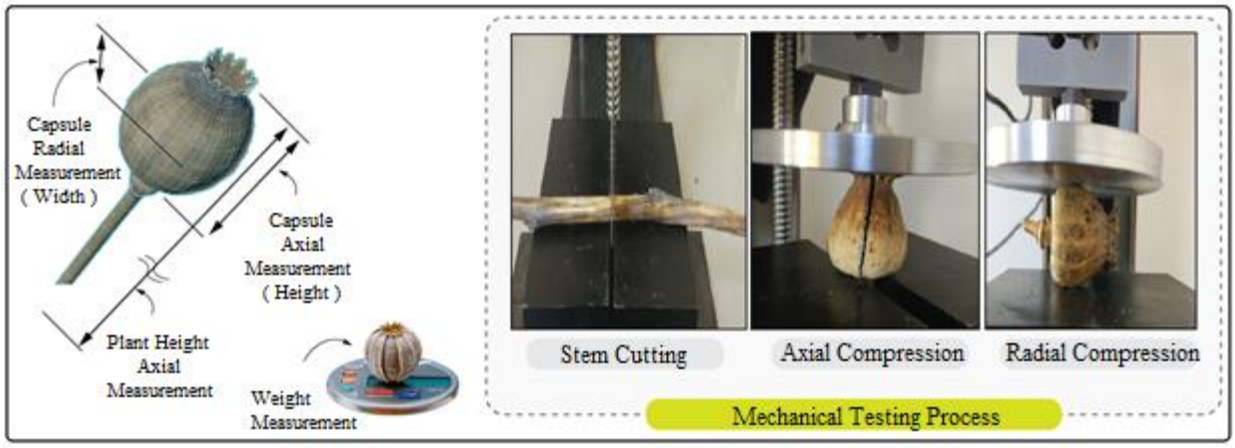

Figure 2. Sample dimensional measurement and mechanical test images

3. Results and discussion

In this study, which focuses on determining certain parameters for the design of harvesting machines, especially the units related to separation, harvesting, collection, threshing, cleaning, transfer, storage, etc., for the blue poppy plant, some physico-mechanical properties of the blue poppy capsule are presented in *Table 1*.

Table 1. Critical Velocity and some physico-mechanical properties of blue poppy capsule

Feature	Average Value ± SD
Height (mm)	37.99 ± 3.18
Width (mm)	35.82 ± 5.75
Mass (g)	5.86 ± 1.62
Volume (mm^3)	300.73 ± 139.9
Horizontal Projection Area (cm^2)	18.66 ± 4.55
Vertical Projection Area (cm^2)	17.91 ± 5.94
Critical Velocity (m s^{-1})	10.22 ± 1.43
Natural Angle of Repose (degrees)	22.86 ± 0.81
Shell Ratio (%)	43.93 ± 2.67

According to *Table 1*; the capsule height is slightly greater than the capsule width. A similar excess is also observed in the footprint area values. This situation indicates that blue poppy capsules tend to develop more longitudinally. The mass, volume, critical velocity, and natural repose angle of the poppy capsule are determined as 2.64 g, 300.73 mm^3, 10.22 m s^{-1}, and 22.85 degrees, respectively. The shell ratio is 43.93%. This value indicates that the amount of seeds in the poppy capsule (56.07%) is higher compared to the shell. Moisture content values of plant parts and products are crucial, especially in determining the harvest time and designing the cutting, threshing, and cleaning units of harvesting machines. Moisture content values for the blue poppy stem and capsule are given in *Table 2*.

As seen in *Table 2*; the average moisture content values for the plant stem and poppy capsule are determined as 7.75% and 7.69%, respectively. The moisture content values in the upper, middle, and lower regions of the plant stem are very close to each other. Therefore, the cutting height with the machine during harvesting can be preferred

from any region of the plant stem. This is a positive feature in terms of harvesting efficiency. Similar observations are present in the moisture content values for seeded and empty poppy capsule. Accordingly; it can be stated that capsule threshing, seed-shell separation, and seed cleaning can be successfully performed. The values for the number of plants, number of capsules, and capsule/plant ratio per unit area for the blue poppy plant are given in *Table 3*.

Table 2. Moisture content values of blue poppy stem and capsule

Plant Part	Feature	Average Value ± SD
Stem	Upper Stem Region Moisture Content w.b.(%)	7.69 ± 2.55
	Middle Stem Region Moisture Content w.b. (%)	7.56 ± 0.68
	Lower Stem Region Moisture Content w.b.(%)	8.03 ± 1.33
	Average (%)	7.76 ± 0.24
Capsule	Seed Capsule Shell Moisture Content w.b.(%)	6.46 ± 0.44
	Empty Capsule Shell Moisture Content w.b.(%)	8.91 ± 0.53
	Average (%)	7.69 ± 1.73

Table 3. Unit area plant count, capsule count, and capsule/plant ratio values

Repetition	Number of plants (piece m^{-2})	Number of capsule (piece m^{-2})	Capsule/Plant ratio (Decimal)
1	36	59	1.6
2	33	53	1.6
3	24	58	2.4
4	33	55	1.7
5	28	51	1.8
Average (piece)	30.8	55.2	1.8
Standard Deviation	4.3	3	0.3

As seen in *Table 3*, considering the repetitions, the total number of plants per unit area varies between 24-36 plants m^{-2}, the total number of capsules ranges from 51 to 59 capsules m^{-2}, and the capsule/plant ratio varies between 1.6-2.4. On average, these values are 30.8 plants m^{-2}, 55.2 capsules m^{-2}, and 1.8, respectively. Therefore, it can be stated that each plant has at least one or more capsules.

In practice, having only one capsule per plant is a desirable feature for both product quality and mechanization success. Uniformity in plant heights is crucial for reducing harvesting losses in machine harvesting. The number of plants per unit area according to plant height groups for the blue poppy plant is provided in *Table 4*.

Table 4. Number of plants per unit area according to plant height groups

Repetition	Plant height groups					Total number of plants
	<85 cm	86-105 cm	106-125 cm	126-145 cm	146 cm>	(count m^{-2})
1	2	6	13	12	3	36
2	0	4	12	13	4	33
3	1	3	9	10	1	24
4	2	6	11	11	3	33
5	1	4	11	10	2	28
Average (count m^{-2})	1.2	4.6	11.2	11.2	2.6	30.8
Total (count m^{-2})	6	23	56	56	13	154
Ratio (%)	3.9	14.9	36.4	36.4	8.4	100

As shown in *Table 4*, the total number of plants per unit area varies between 24 and 36. On average, this value is 30.8. Considering the repetitions, the highest number of plants per unit area based on plant height groups is equal, with 56 plants m^{-2} (36.4%) in the 106-125 cm and 126-145 cm height groups. Following these, the 86-105 cm group (23 plants m^{-2}, 14.9%), the group larger than 146 cm (13 plants m^{-2}, 8.4%), and the group smaller than

85 cm (6 plants m^{-2}, 3.9%) come in order. Taking into account the positive effect of the common moisture values in the plant stems in *Table 2*, choosing a cutting height in machine harvesting below 85 cm can significantly reduce harvesting losses. On the other hand, standardizing the heights of poppy plants through breeding efforts will contribute significantly to the efficiency of mechanization processes.

Having each poppy plant with only one capsule is crucial for both product quality and the success of mechanization processes. The number of plants per unit area according to capsule count groups for the blue poppy plant is provided in *Table 5*.

Table 5. Number of plants per unit area according to capsule count groups

Repetition	Capsule count groups				Total plant count
	1	2	3	4+	(count m^{-2})
1	23	6	4	3	36
2	21	6	4	2	33
3	7	5	7	5	24
4	20	6	5	2	33
5	15	6	4	3	28
Average (count m^{-2})	17.2	5.8	4.8	3	30.8
Total (count m^{-2})	86	29	24	15	154
Ratio (%)	55.9	18.8	15.6	9.7	100

As seen in *Table 5*, the total number of plants per unit area varies between 24 and 36. The average value is 30.8. Considering the capsule count groups based on repeated observations, the highest plant density is predominantly in the single-capsule group, determined as 86 plants m^{-2} (55.9%). Following this, there are the 2-capsule group (29 plants m^{-2}, 18.8%), the 3-capsule group (24 plants m^{-2}, 15.6%), and the 4 or more capsule group (15 plants m^{-2}, 9.7%). In other words, the majority of plants have a single capsule. This situation represents a positive feature for mechanization processes. On the other hand, conducting breeding studies to make each poppy plant single-capsuled will contribute significantly to the efficiency of both product quality and mechanization processes.

The information on stem cutting force and poppy capsule crushing force is crucial, especially for the design and improvement of mechanized harvesting units, particularly the cutting and threshing units. The values of stem cutting force and poppy capsule crushing/pressing force for the blue poppy plant are provided in *Table 6*.

Table 6. Cutting force values for blue poppy stem and capsule

Plant part	Parameter	Mean ± SD
Stem	Cutting force in the upper stem region (N)	31.14 ± 12.10
	Cutting force in the middle stem region (N)	60.01 ± 15.07
	Lower stem region cutting force (N)	74.06 ± 27.26
Capsule	Vertical pressing force (N)	159.39 ± 48.46
	Horizontal pressing force (N)	110.46 ± 15.35

As seen in *Table 6*, the cutting force values for the stem are determined as 31.14 N, 60.01 N, and 74.06 N for the upper, middle, and lower stem regions, respectively. The cutting force values increase from the upper region to the lower region, and there is significant variation in these values in each region. This situation should be taken into consideration in the design of the harvesting unit, particularly to perform cutting from the upper stem region as much as possible due to the lower cutting force, considering the lowest capsule height (refer to *Table 4*). In other words, when designing and improving the mechanized harvesting unit for poppy plants, capsule height and cutting force values should be considered.

The horizontal and vertical capsule compression/breaking force values are determined as 159.39 N and 110.46 N, respectively. The horizontal compression force value is lower compared to the vertical compression force value. These values should be utilized, especially in the design of the threshing unit, for features such as breaking capsules, separating seeds from shells, and determining operating parameters of the threshing unit.

4. Conclusions

In this study, various physico-mechanical properties of the blue poppy plant have been examined. According to the obtained results, the height of the poppy capsule is 37.99 mm, width is 35.82 mm, mass is 5.86 g, volume is 300.73 mm^3, horizontal projection area is 18.66 cm^2, vertical projection area is 17.91 cm^2, critical velocity is 10.22 m/s, natural pile angle is 22.86 degrees, and the shell ratio is 43.93%. During the harvest period, the moisture values of the upper, middle, and lower regions of the poppy stem were measured as 7.69%, 7.56%, and 8.03%, respectively. The moisture content of the empty poppy capsule is 8.91%, and the moisture content of the seeded capsule is 6.46%. The total number of plants per unit area in the poppy field ranges from 24 to 36 plants m^{-2}, the total number of capsules is between 51 and 59 capsules m^{-2}, and the capsule/plant ratio varies between 1.6 and 2.4. On average, these values are 30.8 plants m^{-2}, 55.2 capsules m^{-2}, and 1.8, respectively. According to plant height groups, the highest plant density is 56 plants m^{-2} (36.4%) in the 106-125 cm and 126-145 cm height groups. Then, the 86-105 cm group (23 plants m^{-2}, 14.9%), the group larger than 146 cm (13 plants m^{-2}, 8.4%), and the group smaller than 85 cm (6 plants m^{-2}, 3.9%) follow. The average plant height is calculated as 119.7 cm. According to capsule count groups, the highest plant density is primarily 86 plants m^{-2} (55.9%) in the 1-capsule group. Then, the 2-capsule group (29 plants m^{-2}, 18.8%), the 3-capsule group (24 plants m^{-2}, 15.6%), and the 4+ capsule group (15 plants m^{-2}, 9.7%) follow. The cutting force values for the stem are determined as 31.14 N, 60.01 N, and 74.06 N for the upper, middle, and lower stem regions, respectively. The horizontal and vertical capsule compression/breaking force values are determined as 159.39 N and 110.46 N, respectively.

In conclusion, this study reveals some physico-mechanical properties and critical velocity values of blue poppy plant. These properties will serve as a valuable resource for the design and development of harvesting machines for the mechanical harvesting of blue poppy plants.

Ethical Statement

There is no need to obtain permission from the ethics committee for this study.

Conflicts of Interest

We declare that there is no conflict of interest between us as the article authors.

Authorship Contribution Statement

Concept, Design, Data Collection or Processing, Statistical Analyses, Literature Search: Güngör, O. Writing, Review and Editing, Fiction: Akıncı, İ.

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