Design and Prototype Development Of A Harvesting Machine Mower For Poppy (Papaver Somniferum L.) Plant

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Article

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Abstract

In this study, a capsule-oriented prototype machine for mechanical harvesting of poppy (Papaver somniferum L.) was developed and its design features and performance were evaluated. In Turkey, poppy cultivation is mostly carried out in small plots and harvesting operations are usually carried out manually. This situation both increases the need for labor and leads to crop losses. The prototype machine has been designed to provide a solution to these problems, including a carrier brush, a pulling brush and a three-point circular cutting system. During the design process, the physico-mechanical properties of the poppy plant were determined and cutting blade placements and motor selections were made in line with these properties. The harvesting success of the machine was analysed under different plant heights and capsule numbers through experiments conducted under laboratory and field conditions. The highest success rate was obtained especially in the cuts made at 0-25 mm internode stem length. It was determined that the circular cutting system worked with lower force and more efficiently compared to vertical cutting. In addition, the AC and DC motor systems used in the machine optimized the plant transport and capsule cutting processes by providing different speed and direction controls. The results show that the prototype machine is successful in terms of both efficiency and quality and can be applied in wider areas by integrating automatic feed systems in the future. This study presents an original application that will contribute to the spread of modern mechanization in poppy agriculture.

1. Introduction

Poppy (*Papaver somniferum L.) is* an annual crop plant belonging to the Papaveraceae family with high economic and pharmaceutical value. In addition to being one of the basic raw materials of the pharmaceutical industry thanks to its alkaloids such as morphine, codeine and tebain, this plant draws attention with the use of oils obtained from its seeds in many industries such as food, cosmetics and biodiesel (Yücelşengün et al., 2020; Cesur et al., 2021). It has also been determined that poppy seeds have high antioxidant capacity (Şahin and Bursal, 2023). Turkey has accumulated significant experiences in terms of both legal regulations and agricultural practices in poppy cultivation and opium production in the historical process and has been recognized by the United Nations as one of the legal producing countries (Başlamışlı, 2021). In this context, Turkey maintains its leadership in this field with 64% of the world's poppy cultivation area (TMO, 2019).

Poppy production is a process that needs to be optimized not only in terms of quantity but also quality. Morphine and similar alkaloid contents are directly related to genetic variations, climatic factors and agricultural management practices (Hope et al., 2020; Krošlák et al., 2017; György et al., 2022). Therefore, the harvesting process is as important as the cultivation of the poppy plant. Especially in terms of alkaloid contents, the timing, method and application of harvesting play a critical role in terms of plant yield and substance loss (Yanardağ et al., 2024).

In Turkey, poppy harvesting is mostly done manually, which brings problems such as high labor requirements, low productivity and increased costs (Hacıyusufoğlu, 2013). On the other hand, since poppy is usually grown in small plots, there are incompatibilities in the use of large-scale mechanized harvesting machines. Variability in plant height and irregularities in land structure negatively affect machine efficiency (Kadıoğlu, 2007). Nevertheless, special adapters and mowers developed for poppy harvesting in European countries reduce labor costs and increase efficiency in capsule harvesting (Németh, 1998; Özarslan et al., 2018).

One of the important advantages of mechanical harvesting systems is the even and uniform separation of ripe capsules from their stems (Sproll et al., 2006; Yamaguchi et al., 2010). However, some mechanical systems also mix capsule fragments and stalk remnants into the content during the seed sorting stage, which can cause quality control problems, especially in pharmaceutical production (Földesi, 1992).

In this context, especially for countries like Turkey where small production plots are widespread, the development of capsule-focused, simplified but effective systems in poppy harvesting is a priority. In the study conducted by Özarslan et al. (2018), a prototype machine that can harvest poppy plants, separate the capsule from the stem, is suitable for domestic production and can be used in medium-sized lands was designed. This machine was evaluated in terms of mowing quality, stem-capsule separation and mechanical compatibility and was positioned as a step that will contribute to the widespread mechanization of poppy cultivation. Since poppy is a sensitive plant, the design of the harvesting machine is important. In their study, Sonavane et al. conducted studies for similar products. Field evaluations were made to evaluate harvest efficiency, chopping losses and field capacity at different forward and blade speeds (Sonavane et all., 2025).

The main objective of this study is to present the design and production process of a system for capsule harvesting only, which is suitable for the mechanical harvesting difficulties encountered in poppy production in Turkey. The prototype developed for this purpose simplifies the harvesting process, reduces the need for labor and offers a technical solution to the producer. The findings obtained can contribute to both national agricultural policies and modern agricultural mechanization practices. In the developed prototype machine; unlike the previous machines, the brush transportation system, pulling brush system and 3-point cutting process were used for the first time.

2. Materials

Unlike previous designs, the developed prototype machine is intended to calibrate each plant to the same size and to minimize the rate of foreign matter and lost matter while doing this process. The flow chart of the operation of the prototype machine is given in Fig. 1.

The closed schematic solid model image of the developed machine is given in Fig. 2.

2.1 Brush Designs

Before developing the prototype machine, the physico-mechanical properties of the poppy plant were determined in the field (Güngör & Akıncı, 2024). Based on the physico-mechanical properties identified, the height and length of the prototype machine, as well as the positions of the carrier brush, pulling brush, and cutting blades, were determined. The solid model views of the designed carrier brush and pulling brush are shown in Fig. 3.

The rotary motion of the brushes was driven by DC motors operating at a constant speed of 30 rpm. In the design of the carrier brush; the length of the brushes and the height of the plants were taken into consideration for the distance between the brushes. The average height of the poppy plant in the field was found to be 115 cm (Güngör, 2023). The height of the carrier brush of the prototype machine was designed by taking this value as reference.

2.2 Cutting Blades

The mowing unit is equipped with 3 cutting blades. The position of the cutting blades used for the three-point cutting process is such that all plant heights of different sizes are brought to the same height until they reach the end of the prototype mowing unit. The task of the 1st blade in the prototype machine is to separate the plant from the soil. Therefore, this blade is mounted at the point where the plant enters the prototype machine (Fig. 4.).

The task of the 2nd blade is to shorten very branched and tall plants, both to separate the branched structure from each other and to shorten the tall plants, so it is mounted under the pulling brush (Fig. 5.).

The task of the 3rd blade is to separate the poppy capsule from the poppy stalk at the knuckle point, which is considered the most efficient point for harvesting. The 3rd cutting blade is placed just below the carrier brush as shown in Fig. 6. In this way, the cutting process was realized from the knuckle point at the bottom of the capsule.

Cutting blade motors were supplied with 220 V AC voltage. Circular cutting method was used for the cutting process. The reason for this is to ensure that the plant stem can continue along the carrier brush after the cutting process without getting stuck. The rotation speed of the cutting blades was determined as 7700 rpm. At this speed, it was determined that the loss was the least and the cutting process was the most suitable (Güngör, 2023).

Güngör and Akıncı (2024) determined the vertical shear values of white poppy plant in their study. Vertical and circular cutting values of 7700 rpm circular white poppy plant are given in Table 1.

Table 1
Circular and vertical shear data

	Vertical cutting	**Circular cutting**	**k constant**	**Constant k at shear**
Rotation	-	7700 rpm	-	-
Advance speed	0.0000833 m/s	20 m/s	-	-
Cutting force (Top)	42 N	3.45 N	0.08	0.005
Cutting force (Medium)	72.5 N	5.18 N	0.07	0.027
Cutting force (Bottom)	129 N	6.48 N	0.05	0.025
Cutting power (Top)	0.0035 W	160 W	3980	248
Cutting power (Medium)	0.0060 W	240 W	2718	1019
Cutting power (Bottom)	0.01075 W	300 W	2572	1286

The equation in 1. was used for the calculation of the vertical cutting force and circular cutting force. For all circular cutting operations, a time period of 1 hour was taken as reference.

$$\mathbf{P_{vertical}} = \mathbf{F_{vertical}}.\,\mathbf{V} => \mathbf{P_{circular}} = \mathbf{F_{circular}}.\,\frac{2\backslash\mathbf{varvec}\pi\,\mathbf{r}}{\mathbf{t}}$$

1

$P_{vertical}$: Vertical cutting power, W

$F_{vertical}$: Vertical shear force, N

V : Cutting speed, m/s

$P_{circular}$: Circular cutting power, W

$F_{circular}$: Circular shear force, N

R : Disk radius, m

T : Time, s

The equation in 2. is used to find the k constant between forces.

$$F_{circular} = k.\, F_{vertical} \qquad (2)$$

$F_{circular}$: Circular shear force, N

$F_{vertical}$: Vertical shear force, N k : Constant between forces

The above-mentioned carrier brush, pulling brush and cutting process from 3 different points stand out as innovative features unlike previous designs.

2.3 Guiding arms and Conveyor belt

In front of the prototype machine, deflector arms were designed to straighten the tilted plants and take them between the conveyor brushes, and behind the machine, a conveyor belt was designed to transport them to the warehouse after harvesting. These designs are shown in Fig. 7.

Since the prototype machine was designed for single row harvesting, a 5 cm stalk entry gap was left after the guiding arms. The conveyor belt motor was supplied with 12 V DC voltage. The distance between the steps to carry the capsule on the conveyor belt to the storage was chosen as 30 cm.

The technical drawing of the designed machine is shown in Fig. 8., the solid model is shown in Fig. 9. and the prototype manufacturing is shown in Fig. 10.

3. Research Findings: Laboratory and Field Trials

Plants of different height and number of capsules were used in the trials. Harvest success was evaluated on the basis of capsule internode cutting rate and loss rate. Laboratory and field conditions were designed separately and prototype performance was tested for each. Different height and number of capsules were based on the study of Güngör (2023). Plants with different number of capsules in the harvesting process are shown in Fig. 11.

A visualization of the experimental design for laboratory conditions is given in Fig. 12.

A visual of the harvesting process in the field is given in Fig. 13.

The appearance of the plant stem and capsule at the end of the harvesting process is given in Fig. 14. As seen in Fig. 14, the plant stem is divided into 3 parts. This provides an advantage over other harvesting methods as it facilitates the incorporation of the plant stem into the soil as fertilizer.

A sample of the harvest results is given in Table 2.

Table 2
Prototype machine harvesting trial result

Poppy size (cm)	**86–105**					
Number of capsules per plant (number)		1	2	3	4+	Witness parcel
Under-node stalk cutting length	0–25 mm [a*]	22	21	15	16	21
	26–50 mm [b]	0	1	3	5	2
	51–75 mm [b]	1	0	2	1	1
	76–100 mm [b]	0	1	2	1	0
	100 + mm [b]	1	1	2	1	0
	Amount of loss (quantity)	2	4	3	3	2
	Loss rate (%)	7.69	14.28	11.11	11.11	7.69
*: The difference between means with the same letter is statistically insignificant (P > 0.01)						

In the experimental design, poppy plant height was taken between 86 cm and 105 cm. Plants with 1,2,3,4 or more capsules and witness plot treatment are shown in separate columns. The most efficient point of harvesting is the node under the capsule. Five different sub-node length classifications were made as 0–25, 26–50, 51–75, 51 – 50, 76–100 and over 100 and a success class was formed. In addition, the amount of loss during the harvesting process was also classified in the table. It has been stated that the yield of morphine and its derivatives obtained from poppy capsule decreases as the length of the stalk under the internode increases (Güngör, 2023).

As seen in Table 2., the highest number of capsules harvested was realized in the 0–25 mm internode stem length mowing/cutting group. In the evaluation made according to the number of capsules in the plant, it can be said that the most successful result was obtained in plants with 1 capsule. The highest harvesting/cutting loss occurred in plants with 2 capsules. The least harvest/harvest loss occurred in plants with 1 capsule. It was also observed that stem length increased as the number of capsules increased.

Güngör (2023) also included the results of other experimental designs in his study. The results of the experimental designs are similar. It can be said that harvest success increases as the number of capsules decreases.

4. Conclusions

In this study, an electronically controlled prototype machine was developed for mechanized harvesting of poppy plants. AC and DC motors were utilised for electronic control, and circuits were made for these motors to rotate in different speeds and directions. A carrier brush design was realized for the prototype machine. Brushes with a length of 3.5 cm were placed on a belt at 0.8 cm intervals to transport the poppy plant. The closed length of the belt is 250 cm. Thanks to the carrier brush, the plant is transported without damage. By increasing the hardness of the brushes placed on the belt, longer brushes can be driven, so that the number of harvest rows can be increased in planting with the row sowing method. By increasing the closed length of the belt, the progress speed can also be increased.

The pulling brushes convey the intercepted plants vertically toward the carrier brush mechanism. In the prototype, the circular cutting method, which is rarely used in harvesting machines, was used. The speed of the motor to which the blade is connected was controlled. In addition, the cutting process was done at three different points. In most of today's harvesting machines, cutting is done from a single point. The design was made to perform the cutting process from three different points. In this way, the calibration process and the harvesting process were more successful. The progress speed can be increased by increasing the length of the carrying brush of the prototype mower, in this case, the number of circular cutting blades can be increased and the length of the carrying brush can be increased and the calibration process in this case can be made more successful.

For the prototype machine, a stepped conveyor belt was designed to transport the harvested capsules to the warehouse. In the front part of the prototype, guiding arms were made so that the tilted plants could be grasped by the carrier brushes. If the length of the conveyor brush and the pulling brush is increased, the distance between the guiding arms can also be increased since the harvesting sequence in row crop fields can be increased.

The prototype machine is manually operated by the user through push-assisted propulsion.

Declarations

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Declaration of Generative AI and AI assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT for grammar and clarity improvements. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Declaration of Interest Statement

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.

This article was produced from the doctoral dissertation of the 1st author.

Data Availability

The datasets generated during the current study are not publicly available due to the absence of a suitable public repository for engineering prototype data but are available from the corresponding author on reasonable request.

Author Contribution

OG wrote the article, collected the data, performed the analyses, and this article was also derived from this author's doctoral thesis. IA performed structural reviews, provided consulting, and made corrections.All authors reviewed the manuscript.

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Figures

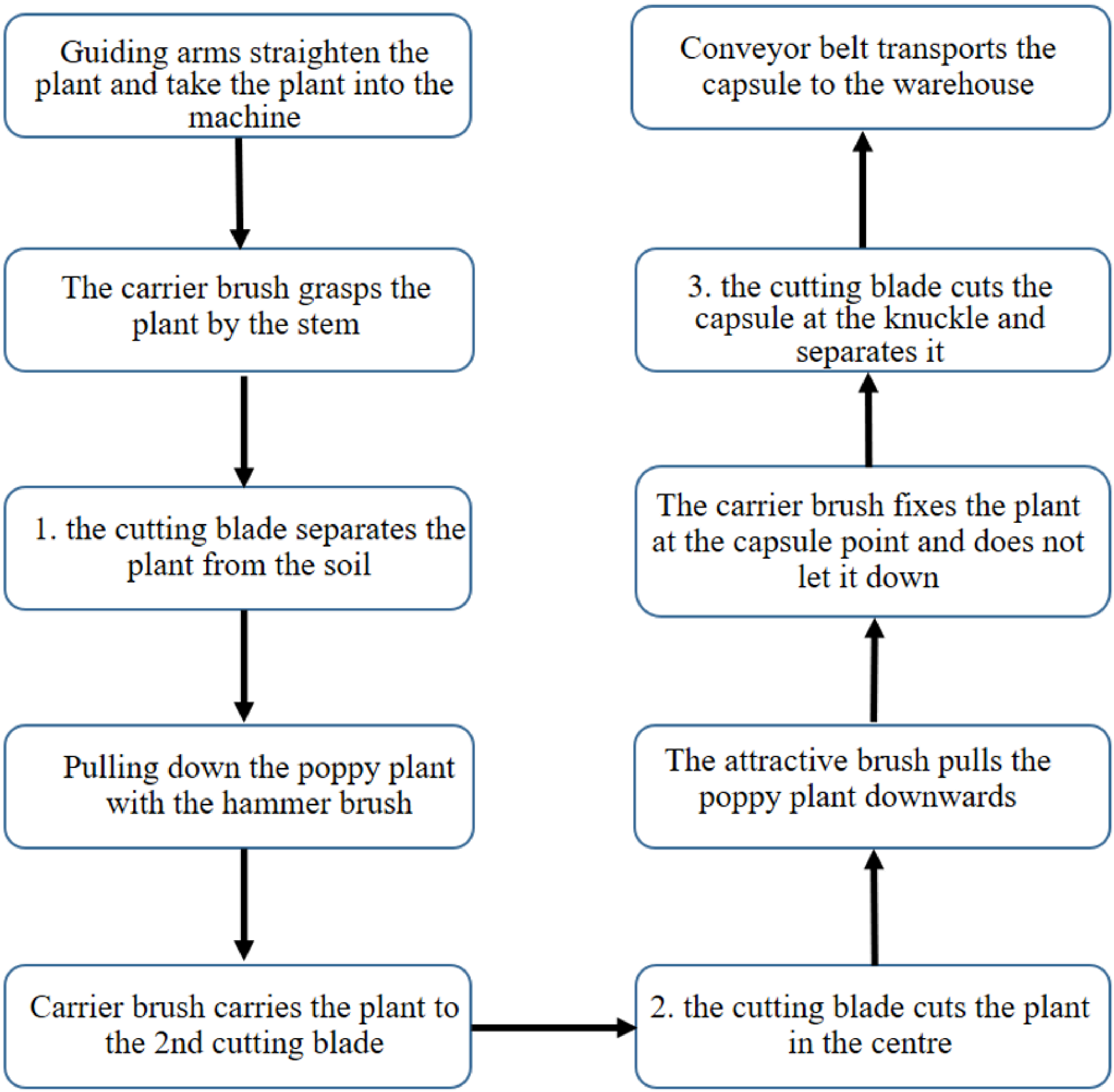

Figure 1

Work flow chart of the prototype machine

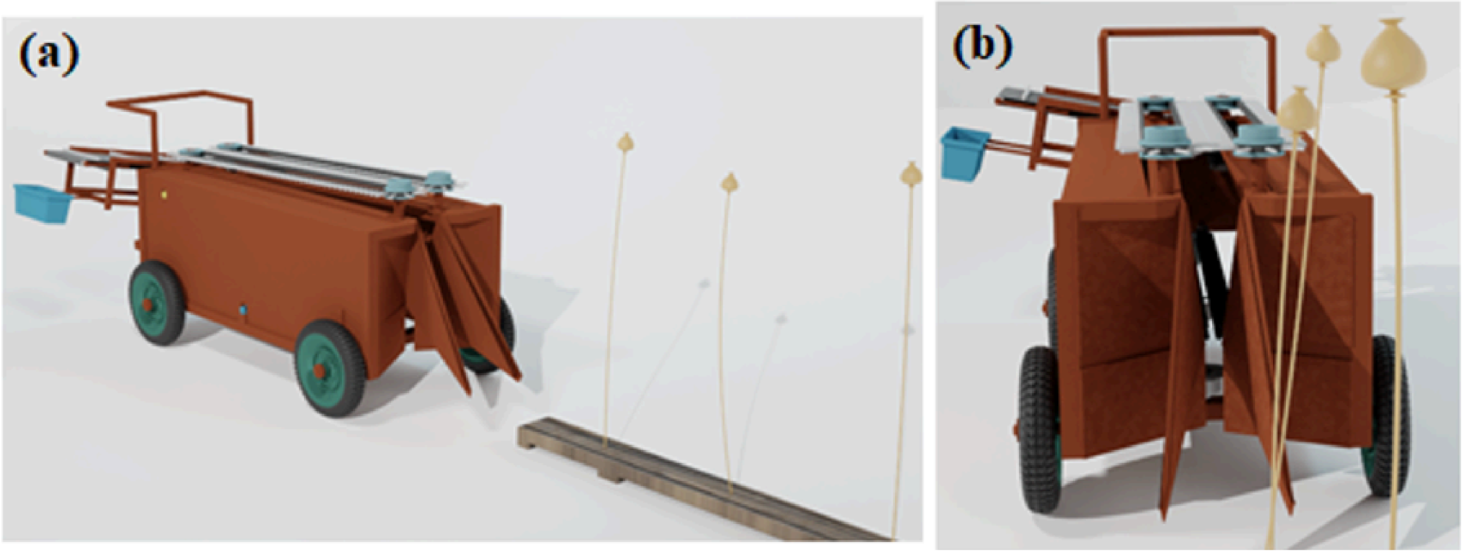

Figure 2

Prototype machine closed schematic solid model: (a) Perspective view, (b) front view

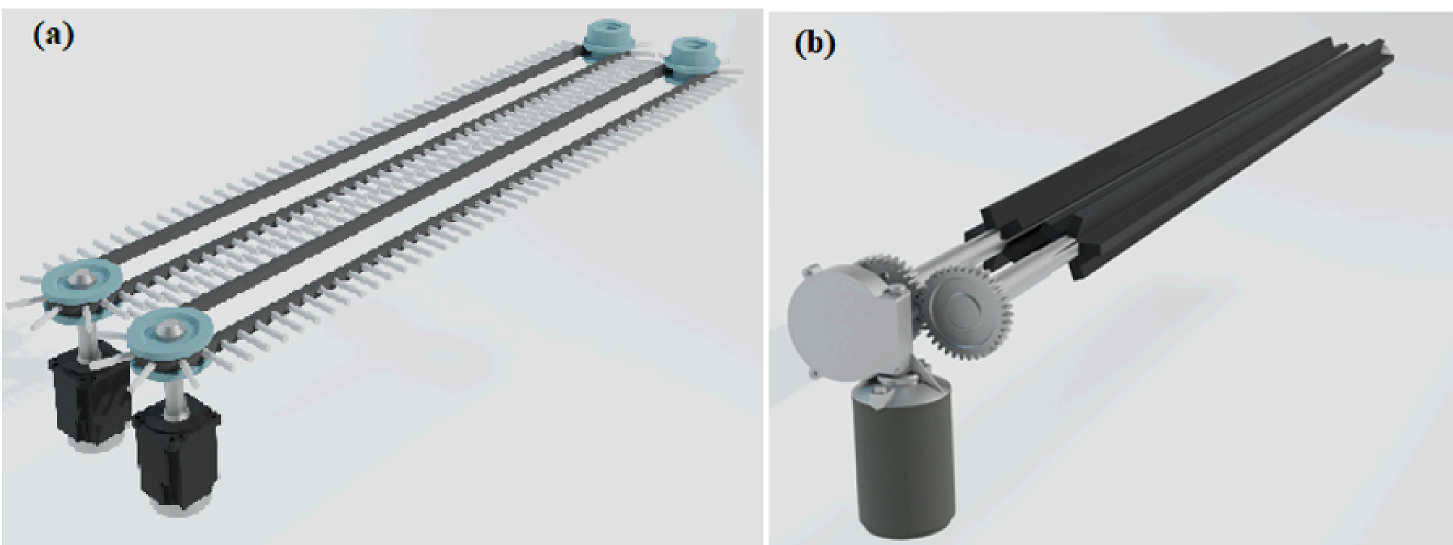

Figure 3

Figure 2. Brush designs: (a) carrier brush, (b) pulling brush

Figure 4

Figure 3. First(1.) cutting blade layout

Figure 5

Figure 4. Second(2.) cutting blade placement

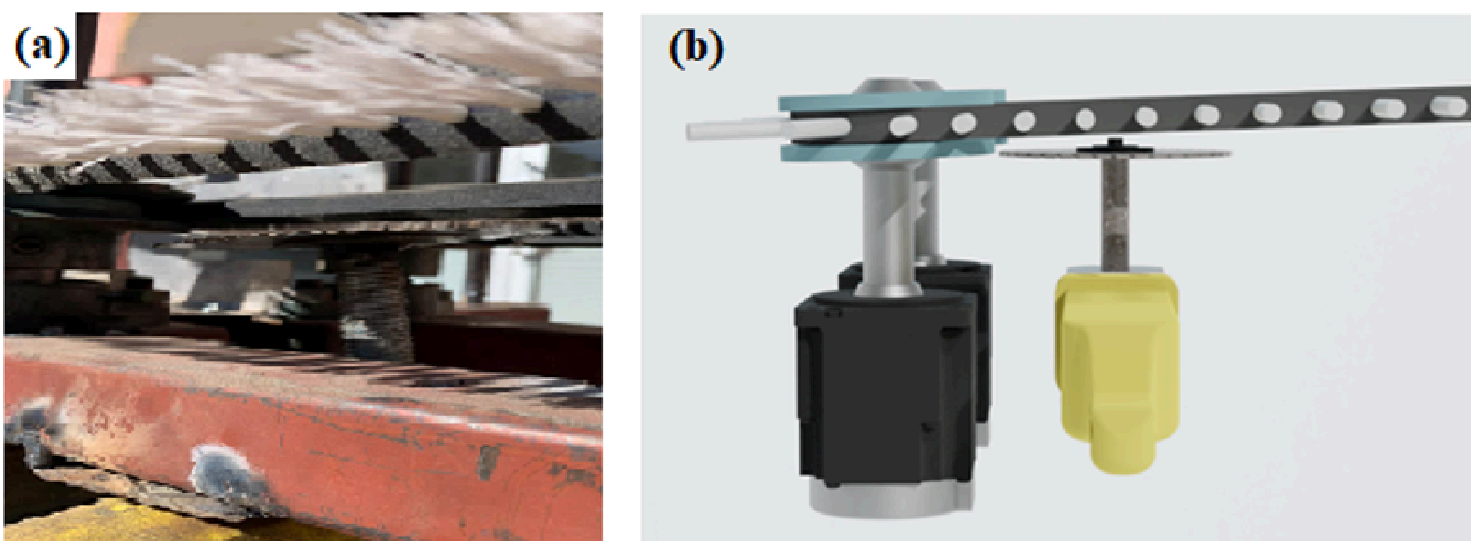

Figure 6

Figure 5. Third(3.) cutter blade layout: (a) realized assembly, (b) solid model view

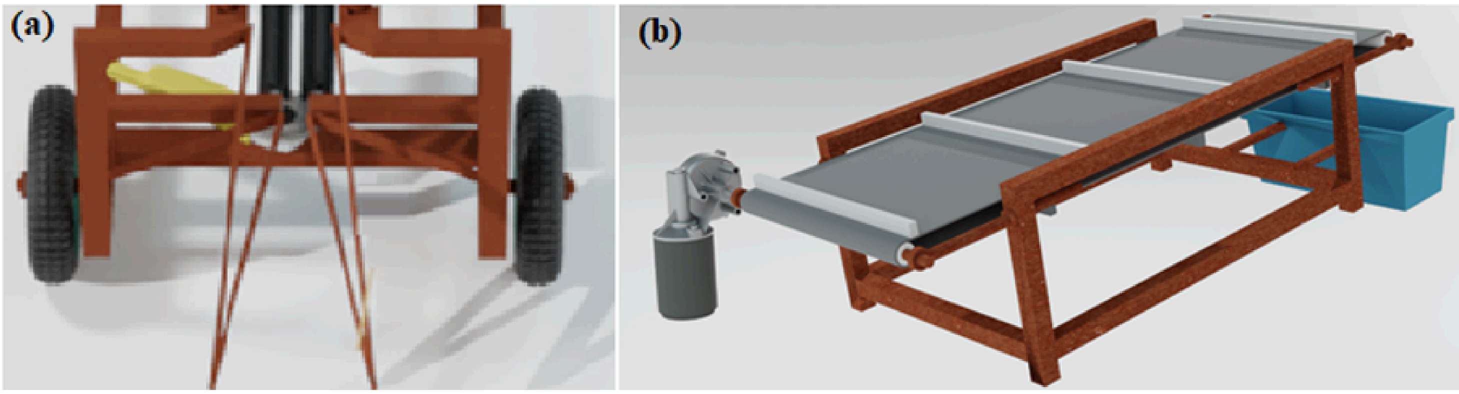

Figure 7

Figure 6. Additional designs: (a) guiding arms, (b) conveyor belt

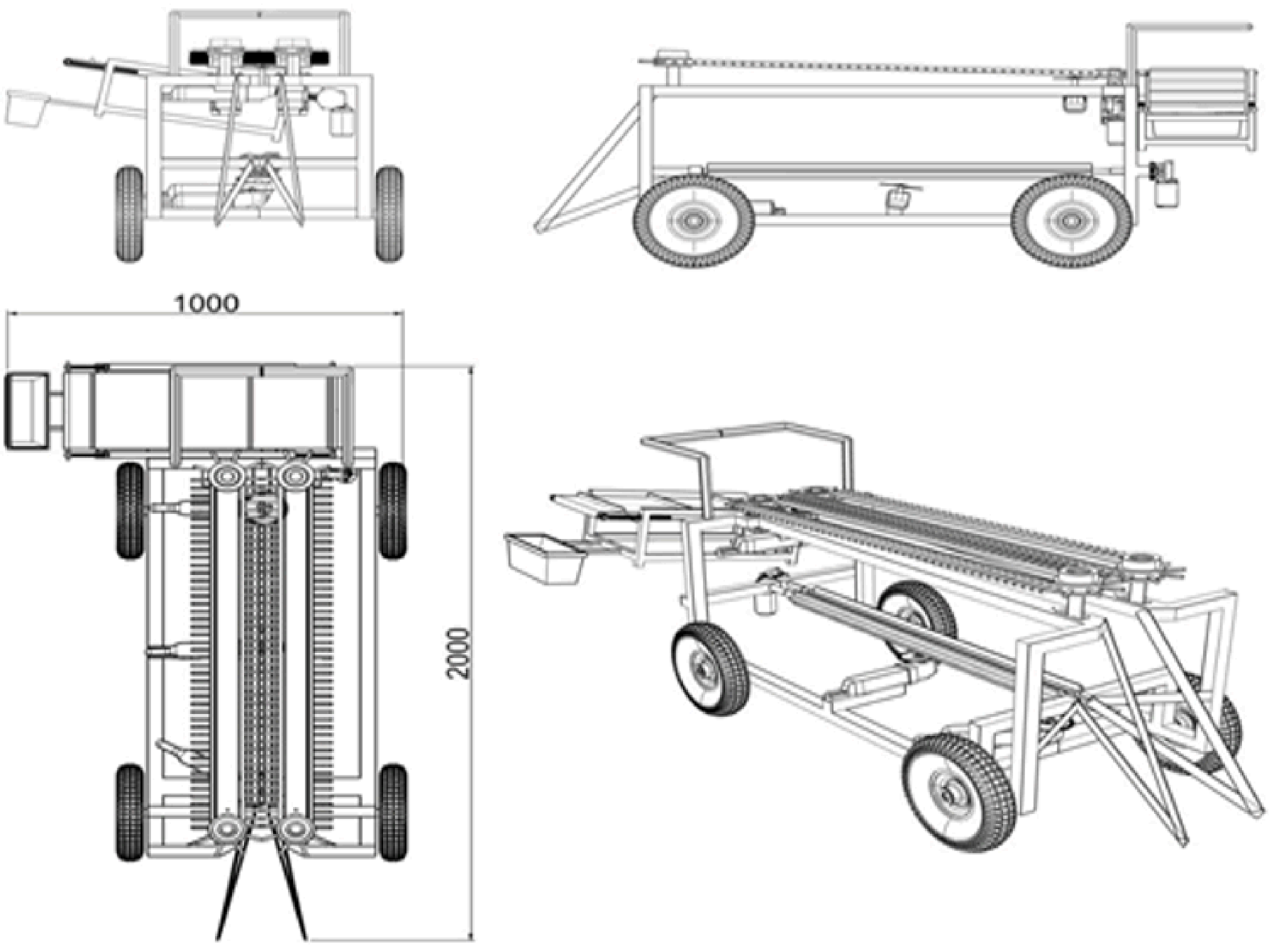

Figure 8

Prototype machine technical drawing

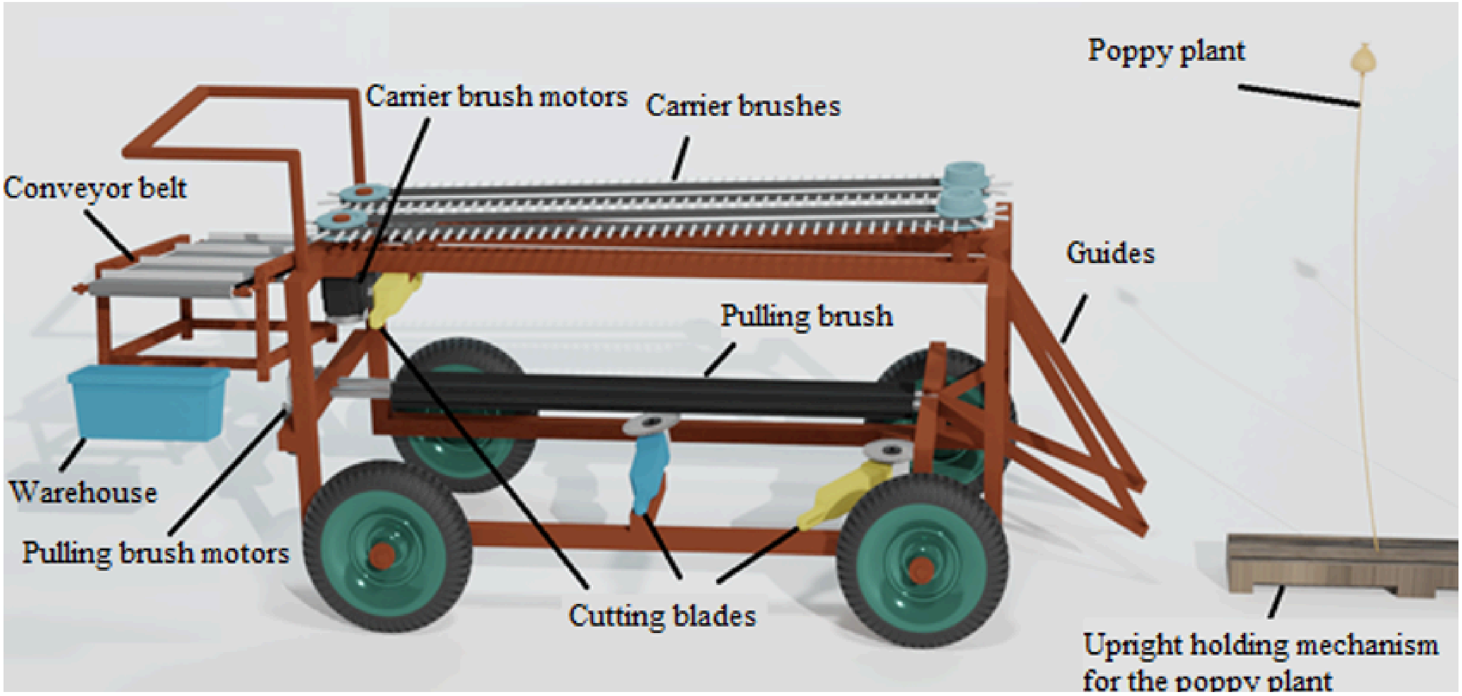

Figure 9

Prototype machine solid model side view

Figure 10

Side view of the prototype machine

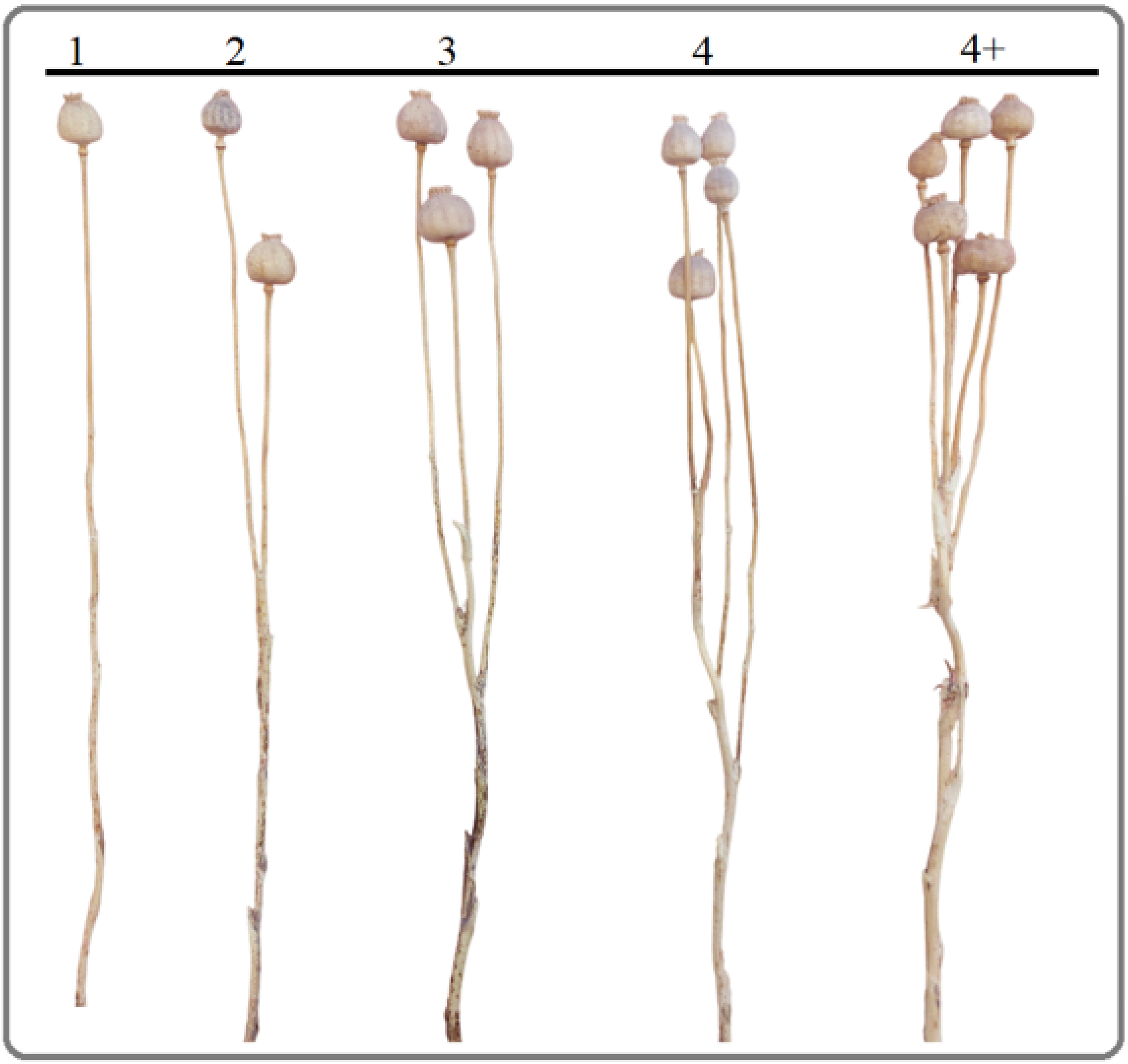

Figure 11

Poppy plants with different capsule numbers

Figure 12

Harvesting process under laboratory conditions

Figure 13

Harvesting process in the field

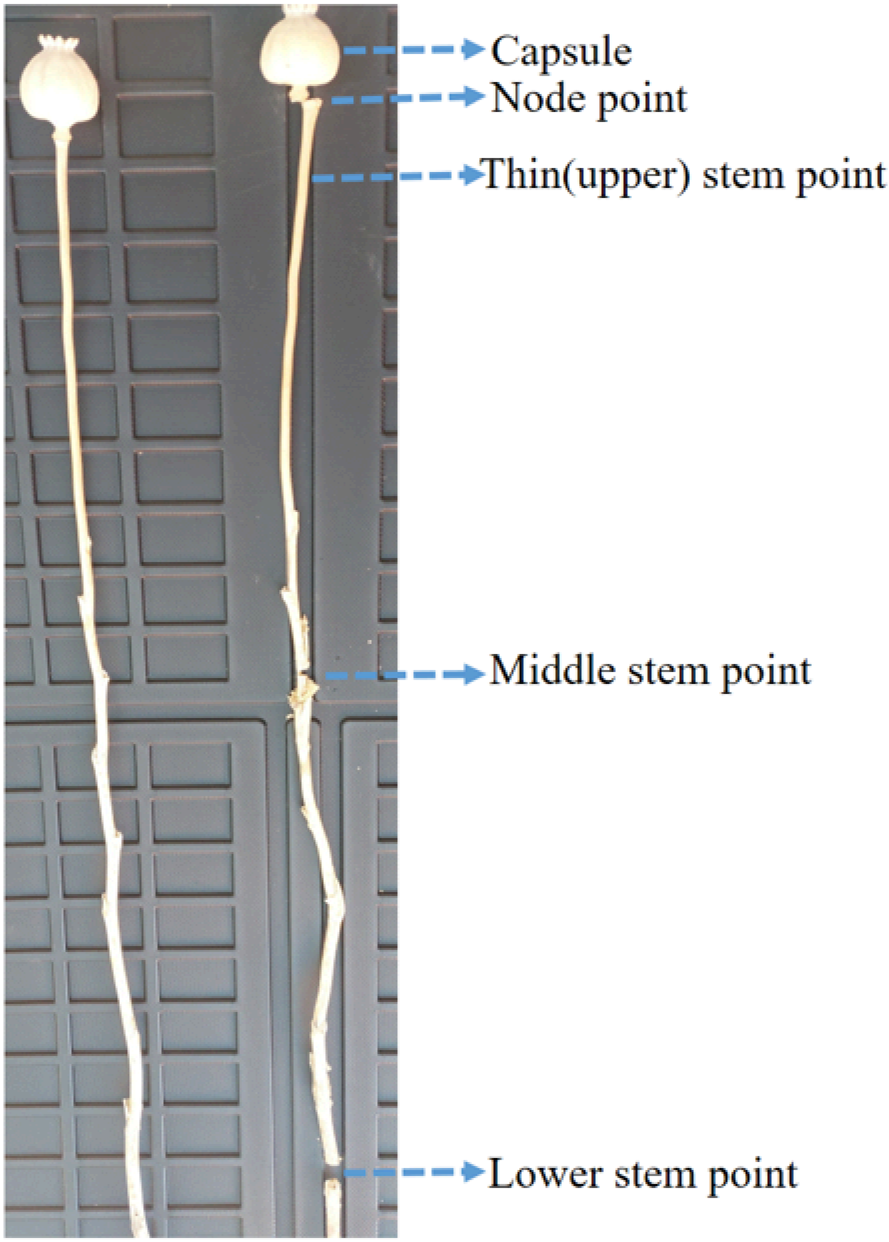

Figure 14

Cutting points of poppy plant

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