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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Design of Lavender Harvesting Machine and Development of Prototype*

Lavanta Hasat Makinasının Tasarımı ve Prototipinin Geliştirilmesi

Mehmet Emin GÖKDUMAN[1*], Deniz YILMAZ[2]

Abstract

The increasing demand for medicinal and aromatic plants in both local and global agricultural markets has heightened the significance of lavender cultivation. To meet this growing demand, there is a need to shift from traditional farming methods to technological production tools and agricultural innovations. In Turkey, lavender harvesting is predominantly carried out manually, which is both labor-intensive and physically strenuous. To enhance commercial productivity, the implementation of mechanized harvesting methods has become essential. In this study, a prototype of a lavender harvester was developed and manufactured, designed to accommodate the characteristics of lavender plants and field conditions, addressing the challenges faced during the harvesting process. The process began with the identification of the machine's functional units and the development of preliminary design drawings. The performance tests of the manufactured harvester were conducted under field conditions, focusing on its cutting and binding capabilities. The test results indicated that the machine achieved an average cutting efficiency of 95.2% and an average binding efficiency of 68.0%. Furthermore, the experiments demonstrated that the harvested lavender could be successfully transferred to a trailer or directly onto the field surface using a conveyor belt system. However, it was identified that alternative binding mechanisms need to be explored, and machine performance should be improved, particularly concerning the bundling process. Addressing these aspects is crucial for enhancing the overall efficiency of the lavender harvester. Mechanizing the harvesting process reduces dependence on manual labor and consequently increases harvest efficiency, contributing to the commercial productivity and sustainability of lavender farming. The lavender harvester developed and manufactured in this study distinguishes itself from existing machines with its customized transportation system, binding unit, and adjustable cutting width. These technological applications enhance the efficiency and effectiveness of lavender harvesting operations. This study represents a significant step towards the mechanization of lavender harvesting and lays the groundwork for future research and development in this field.

Keywords: Harvesting machine, Binding unit, Lavender, Medicinal andaromatic plant, Agricultural mechanization, Türkiye

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Öz

Tıbbi ve aromatik bitkilere olan talebin hem yerel hem de küresel tarım piyasalarında giderek artması, lavanta yetiştiriciliğinin önemini de artırmaktadır. Artan bu talebi karşılamak için, geleneksel tarım yerine teknolojik üretim araçlarının kullanımı ve tarımsal yeniliklere ihtiyaç duyulmaktadır. Türkiye'de lavanta hasadı ağırlıklı olarak insan iş gücüne dayalı olarak yürütülmektedir. Zor ve yorucu olan hasat süreci, ticari üretkenliği artırmak için mekanize hasat yöntemlerinin uygulanmasını zorunlu kılmaktadır. Bu çalışmada, lavanta yetiştiriciliğinde karşılaşılan hasat sorununu çözmek amacıyla lavanta bitkisi ve tarla özelliklerine uyumlu bir lavanta hasat makinesi prototipi geliştirilmiştir. Süreç, makinenin işlevsel ünitelerinin belirlenmesi ve imalat öncesi tasarım çizimlerinin oluşturulmasıyla başlamıştır. Üretilen hasat makinesinin performans testleri, tarla koşullarında gerçekleştirilmiştir. Değerlendirme, makinenin kesme ve bağlama yeteneklerine odaklanmıştır. Test sonuçları, makinenin ortalama kesme verimliliğinin %95,2 ve ortalama bağlama verimliliğinin %68,0 olduğunu göstermiştir. Ayrıca, yapılan deneyler, kesim sonrası hasat edilen lavantanın bir konveyör bant sistemi aracılığıyla başarılı bir şekilde römorka veya arazi yüzeyine aktarılabildiğini göstermiştir. Ancak, bağlama süreci ile ilgili olarak alternatif bağlama mekanizmalarının araştırılması ve makine performansının iyileştirilmesi gereği ortaya çıkmıştır. Bu adımların yerine getirilmesi, lavanta hasat makinesinin verimliliğini artırılması bakımından önemlidir. Hasadın mekanize olması, iş gücüne bağımlılığı azaltır ve buna bağlı olarak hasat verimliliğini artırır. Bu durum, lavanta tarımında ticari üretkenliği artırmak ve lavanta tarımının sürdürülebilirliğini sağlamak açısından önemlidir. Tarafımızdan imalatı gerçekleştirilen lavanta hasat makinesi, özelleştirilmiş taşıma sistemi, bağlama ünitesi ve ayarlanabilir biçme genişliği ile üretilen diğer makinelerden ayrılmaktadır. Bu teknolojik uygulamalar, lavanta tarımında hasat işlemlerini daha verimli ve etkili hale getirmektedir. Çalışma, lavanta hasadının mekanizasyonu konusunda önemli bir adım olup, gelecekteki araştırmalar ve geliştirmeler için bir temel teşkil etmektedir.

Anahtar Kelimeler: Hasat makinesi, Bağlama sistemi, Lavanta, Tıbbi- aromatik bitki, Tarımsal mekanizasyon, Türkiye

1. Introduction

Medicinal and aromatic plants, recognized for their applications in food, pharmaceuticals, cosmetics, spices, as well as in industries such as dye production, landscaping, ornamental plants, and insecticide manufacturing, have been utilized since the dawn of human history. The demand for medicinal and aromatic plants in global markets continues to increase steadily with each passing day. The diverse climate and ecological conditions of our country endow it with substantial economic potential concerning both wild-harvested and cultivated medicinal and aromatic plants. This potential stems from the extensive variety and abundance of plant species present in its flora. Agricultural practices in Turkey serve a dual function, contributing significantly to the conservation of local biodiversity while also serving as a key driver of economic growth. Furthermore, Turkey actively participates in the global market through its involvement in the exportation of medicinal plants (Bayram et al., 2010; Boztaş et al., 2021). While it may be economical to gather certain species from nature, obtaining high-quality and standardized products from wild-harvested plants can be challenging. In medicinal plants, the concept of quality has become more significant than yield. This is because the substances present in the composition of these plants, which are used and effective, are crucial (Korkunç, 2018). Considering that low quality is attributed to damages occurring during harvesting and post-harvest processes (İnce et al., 2016; Sessiz and İnce., 2023). It is suggested that the quality and efficiency of these substances can be enhanced through improvements in mechanization conditions. The diversity of product types and crop production systems will increase with the advancement of comprehensive agricultural mechanization technologies. As a result, the demand for agricultural machinery in the region will increase, driven by the varied agricultural production systems (Özpınar and Çay, 2018).

In the cultivation of medicinal aromatic plants for essential oil production, obtaining essential oils promptly is crucial. Consequently, there has been a need to adopt machines specifically designed and manufactured for medicinal and aromatic plants, integrating advanced technologies and mechanisms to minimize labor requirements. These harvesting practices have necessitated the adoption of machines tailored for medicinal and aromatic plants, incorporating advanced technologies and mechanisms to reduce labor requirements (Bülbül and Yıldırım, 2024).

The number of medicinal and aromatic plant species cultivated worldwide for commercial purposes is 900. Turkey, on the other hand, has approximately 500 species of medicinal and aromatic plants (Arslan et al., 2015). Among these plants, lavender, which holds high economic value, is also included. The most economically valuable parts of the lavender plant are its flowers. Essential oil is extracted from the flowers and leaves of the plant, and lavender essential oil is among the top 15 essential oils in terms of global trade volume. Lavender can be propagated both vegetatively and generatively, with vegetative propagation involving the use of cuttings and rooted shoots from the plants (Aslancan and Sarıbaş, 2011).

The generally perceived challenges in the cultivation and utilization of medicinal and aromatic plants include a lack of technical knowledge and skilled labor in areas such as propagation, cultivation, and harvesting. Additionally, there are quality losses in products due to indiscriminate harvesting from nature. Other significant issues encompass underdeveloped institutional structures such as production associations, cooperatives, and a limited number of enterprises operating at small scales. Furthermore, many of these enterprises operate under primitive conditions. These factors collectively pose as the most prominent obstacles in the medicinal aromatic plant cultivation sector (Kuzgun and Tuğrul, 2014).

The suitability of lavender plants for various regional climates and soil structures, combined with their preference among farmers and entrepreneurs across different sectors, has resulted in an expansion of lavender cultivation areas and subsequently, increased production volumes. However, in the production of medicinal and aromatic plants, harvesting processes often rely on simple cutting hand tools and basic machinery. Although various machines developed for different products are utilized for harvesting medicinal and aromatic plants, this practice frequently results in losses and damages that can diminish both yield and quality, thereby prolonging the harvesting period.

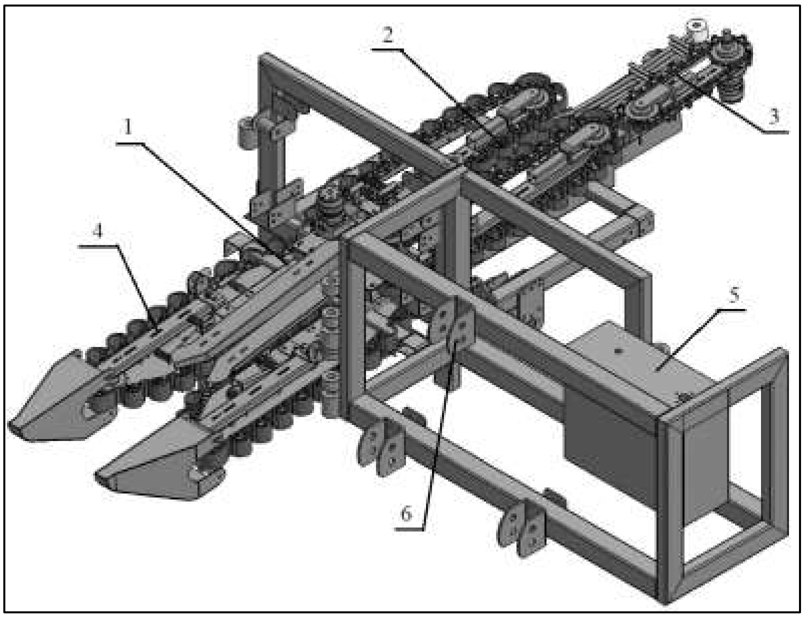
In the agricultural sector, timely completion of tasks is paramount to improving productivity and product quality. Mechanization in agricultural activities not only ensures efficiency but also provides significant labor and time savings (Sessiz et al., 2020; Baykut et al., 2023). As a result, the increase in total acreage and the expansion of lavender fields has led to a steady increase in mechanization practices specific to lavender, including tillage and flower harvesting. (Stanev et al., 2016).

In this study, a design and prototype of a harvesting machine, capable of being attached to a tractor and used in small, medium, and large production areas, have been developed to address the harvesting mechanization challenge encountered in lavender cultivation. The aim of this study is to reduce the need for labor and minimize losses and damages. The lavender harvesting machine, developed based on literature review and user requirements accepted by machine manufacturers, performs the operations of cutting lavender, transporting it vertically, and binding it into bundles at the binding unit during the harvesting period. The lavender harvesting machine consists of four main units: the cutting unit, product conveyor unit (corrugated belt system), binding unit, and control unit. With a customized transport system, binding unit, and adjustable cutting width, the machine ensures that lavender plants are dropped onto the field surface in bundled form.

2. Materials and Methods

2.1. General structure of lavender harvesting machine

The prototype lavender harvesting machine consists of four main units: the cutting unit, product conveyor unit (corrugated belt system), binding unit, and control unit. The machine is mounted on tractor by the three-point hitch system (*Figure 1*).



1. Cutting system 2. Corrugated conveyor system 3. Binding unit 4. Product guiding mechanism 5. Control unit 6. Three-point hitch system

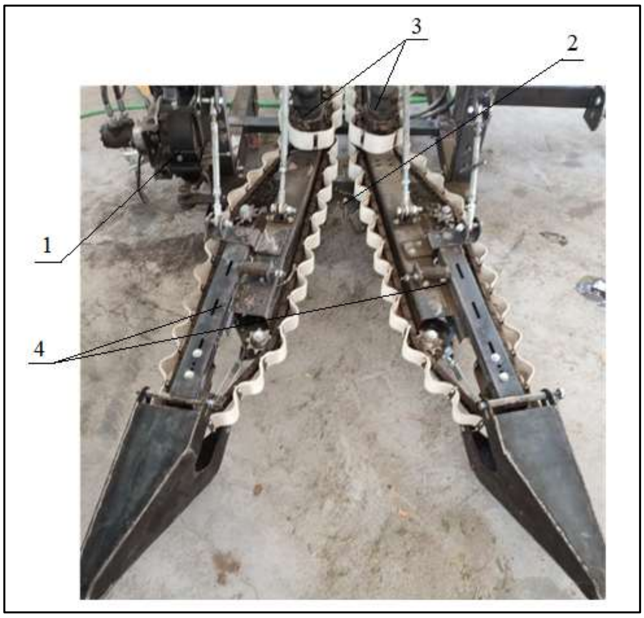
Figure 1. General structure schematic of lavender harvesting machine

2.2. Design of key components

2.2.1. The guiding arms and cutting unit

The cutting unit enables the lavender branches to be cut and transferred to the conveyor unit. The cutting arrangement consists of separators that guide the lavender plants vertically towards the cutting knifes, ensuring alignment with the crown structure of the plants, and guiding arms carrying the chain gear system. The cutting unit is shown in *Figure 2*.

The reciprocating cutterbar is a key component of a mechanical harvester, and its cutting performance directly affects both the power consumed during cutting operation and the quality of the crop harvested by the machine (Du et al., 2022; Sessiz and İnce, 2023). The structural parameters of the knife play a crucial role for determining the power consumption and reliability of the cutting mechanism. In particular, when determining the width of the knife, the cutting angle (α) is a critical factor that determines the length of the knife and affects both clamping stability and cutting resistance (Jiang et al., 2013; Huang et al., 2020; Sessiz and İnce., 2023). The knifes on the knife arm, which are driven by the crank-slider mechanism to provide reciprocating motion, facilitate the cutting of the product. The reciprocating motion of the cutting knifes is achieved through a hydraulic motor via a motion range reducer. Before being transferred to the knife, the rotational motion is converted into linear motion through a linear motion reducer. The cutting knifes are made of resilient, serrated material resistant to deformation. Positioned at the intersection of angled arms on a knife, they facilitate the collection of products at a single point on the knife. The cutting width is adjustable based on the product density and the desired bundle diameter.



1. Cutter arm reducer 2. Cutting knifes 3. Hydraulic motors 4. Guiding arms

Figure 2. General structure of guiding arms and cutting unit

2.2.2. The product conveyor system

In the conveyor system, the harvested products are transported to the binding unit by the product conveyor unit consisting of a vertically positioned chute system. As the plants are cut, they are simultaneously guided by the guide

Figure 3. Product conveyor unit

arms, which transport the cut stalks to the binding unit located at the rear of the machine (Sidahmed and Jaber, 2004). The profiles carrying the chain sprocket systems, product conveyor belt, and hydraulic motors, which are positioned after the mowing unit, are arranged at an angle. For the assembly of the corrugated conveyor belt in the product conveyor unit, a total of 5 650 mm length transmission chain is used, with 2 825 mm on each of the two guiding arms. The chains are driven by sprockets with 1/2" single row and 15 teeth. Additionally, there is a tensioning mechanism for the chain-sprocket system adjustment. The manufacturing drawing of the product conveyor system is provided in *Figure 3*.

The hydraulic motors that operate the cutting knifes also drive the chain-sprocket mechanism located in the product conveyor unit simultaneously

2.2.3. The binding system

An independent chain-sprocket system is used in the binding unit. Products conveyed from the stalk section by the corrugated belt system are stopped in a chamber to carry out the binding process. The chambers where the products are stopped and connected are formed by tubular profiles placed on the chain links. There is a router placed at an angle opposite the chain system for compacting and accumulating the lavender bundle in the chambers. After the products reach a certain density, the routers that move with the spring mechanism give a warning to the sensor and the system is stopped and the binding process is carried out. The manufacturing drawings of the binding unit are provided in *Figure 4*.

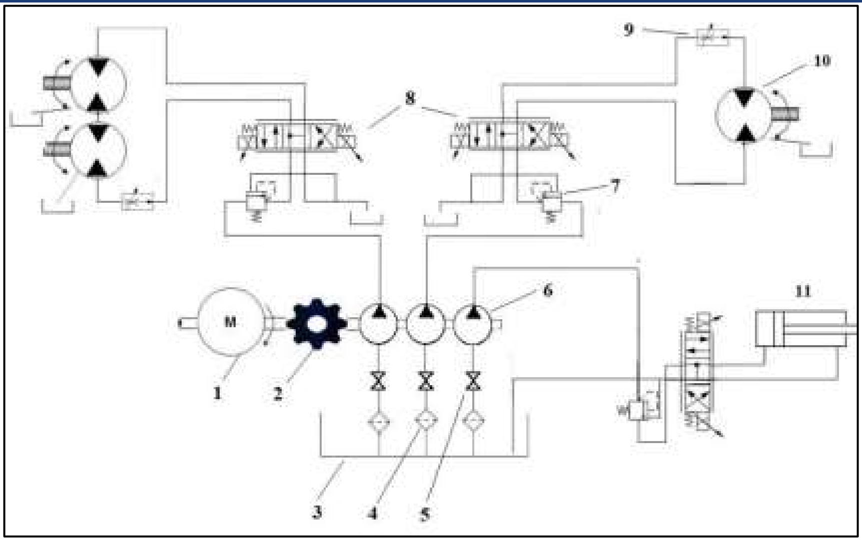
Figure 4. Binding unit

The start-stop motion of the chain-sprocket system in the binding unit is provided through an electronic control unit and software using a pressure sensor. Low-density polyethylene (LDPE), also known as stretch film, is used as the binding material.

2.2.4. Motion transmission mechanism and power

Hydraulic systems are used in as many places as possible, because hydraulic power is easily accessible from the tractor (McGuinness et al., 2023). A hydraulic system that works by taking motion from the tractor tail shaft is used for machine motion transmission. Hydraulics are used to move the sprocket mechanisms, operate the guiding arms, give movement to the product conveyor unit and the binding unit. Gearboxes, directional gearboxes, crank mechanisms, chain and sprocket mechanisms, hydraulic systems and equipment are used to transmit motion. The hydraulic circuit diagram of the machine is given in *Figure 5*.

The motion taken from the tractor is distributed to the hydraulic oil pumps by means of a speed increase gearbox. The motion taken from the tractor's PTO shaft at a speed of 540 rpm was increased to 1500 rpm with a ratio of 1:3 using the speed increase gearbox. A series of 3 hydraulic pumps were connected in series to the speed increase gearbox. The hydraulic pumps transfer fluid filtered from the 100-liter hydraulic oil tank to the hydraulic motors and pistons by passing through speed, pressure and direction control valves.



1. Power take-off 2. Speed increaser gearbox 3. Oil tank 4. Hydraulic valve 5. Filter 6. Hydraulic pomp 7. Pressure limiting valve 8. Directional control valve 9. Adjustable flow control valve 10. Hydraulic engine 11. Double-acting hydraulic cylinder

Figure 5. Hydraulic circuit diagram

2.2.5. Electronic control unit

The electronic control unit consists of a specially designed circuit board and a control panel. The power required for the control unit is supplied by the tractor battery. The control unit manages the lavender harvester's cutting system, guiding system, product conveyor system (or optional conveyor belt), binding unit, and various hydraulic cylinders through hydraulic control valves.

2.3. Field trials of lavender harvesting machine

2.3.1. Experimental area

The machine was tested in a 5-decare lavender field located in Keçili Village, Gelendost District, Isparta Province. Gelendost district, with an area of 624 km², has an average elevation of 940 meters above sea level (Özen, 2019).

2.3.2. The cutting efficiency

The cutting unit, which was designed and manufactured, was tested under field conditions to determine its effectiveness. The machine, attached to the tractor's three-point hitch system, was operated at speeds of 3, 5 and 8 km h^{-1}. After the harvesting process, uncut products on the lavender mound were collected and weighed. The cutting efficiency was determined by the ratio of the weight of the harvested products to the total product weight in the lavender mound, as described by Mady et al. (2015). The cutting efficiency (Ec) was determined using Equation (1).

$$\mathrm{E}_c = \mathrm{H}_a/\mathrm{T}_a x\ 100 \quad \text{(Eq.1)}$$

where,

Ec: the cutting efficiency (%),

Ha: the harvested product amount (g),

Ta: the total amount of product in the lavender cluster (g).

2.3.3. The binding efficiency

The efficiency of the binding unit is calculated by the ratio of the total weight of bundled products to the amount of harvested product. It is determined using Equation (2) (Mady et al., 2015).

$$\mathrm{E}_b = \mathrm{B}_a/\mathrm{H}_a x\ 100 \quad \text{(Eq.2)}$$

where,

Eb: the efficiency of the binding unit (%), Ba: the amount of bundled product (g),

Ha: the amount of the harvested product (g).

2.3.4 Determination of machine performance

With the prototype machine (*Figure 6*), the following values were determined at speeds of 3, 5 and 8 km h^{-1} during the 1st harvest (H1), 2nd harvest (H2), and 3rd harvest (H3) in August 2022, when the temperature ranged from a minimum of 18°C to a maximum of 34°C: machine field capacity (ha h^{-1}), machine work capacity (kg h^{-1}), draft force (N), draft power (kW), and PTO power (kW).

Figure 6. Field experiment

The average speed of the knife (Sb_{ort}), which moves back and forth in the cutting mechanism connected to the eccentric mechanism, is calculated using the following Equation (3) (Dinçer, 1971).

$$\mathrm{Sb}_{ort} = 2\mathrm{Sn}/60 = \mathrm{Sn}/30 \quad \text{(Eq.3)}$$

where,

Sb_{ort}: the speed of the knife (m s^{-1}),

S: the knife stroke (g),

n: the number of revolutions of the eccentric giving motion to the knife (rpm).

The field capacity of the machine (C_f), defined as the area harvested per unit time, is determined by the following Equation (4) (Mandal et al., 2016; Goyal and Singh, 2020):

$$\mathrm{C}_f = \mathrm{A}_h/\mathrm{t} \times 0.75 \quad \text{(Eq.4)}$$

where,

C_f: the field capacity of the machine (da h^{-1}),

Ah: harvested area (da),

t: the operating time (h) (Field efficiency value is taken as 0.75).

The work capacity of the machine (C_w), defined as the amount of product harvested per unit time, is determined by the following Equation (5) (Mandal et al., 2016; Nawi et al., 2024):

$$\mathrm{C}_w = \mathrm{H}_a/t \quad \text{(Eq.5)}$$

where,

C_w: the work capacity of the machine (kg h^{-1}),

H_a: the harvested product amount (g), t: the operating time (h).

The draft power (P_d) value of the machine is determined by the following Equation (6) using the draft force values obtained with the dynamometer used in the experiments (Tezer and Sabancı, 1997; Goyal and Singh, 2020):

$$P_d = F_d . V/1000 \quad \text{(Eq.6)}$$

where,

P_d: the draft power requirement of the machine (kW),

F_d: the draft force (N),

V: the forward speed of the tractor (m s^{-1}).

The PTO power values of the machine (P_{pto}) were measured with a torque meter used in the experiments. The obtained values were verified using the following equation (7) (Sabancı et al., 2010; Mandal et al., 2016):

$$P_{pto} = T_p . n/9550 \quad \text{(Eq.7)}$$

where,

P_{pto}: the PTO power (kW),

T_p: the PTO tork (N),

n: the PTO speed (rpm).

2.3.5. Determining the moisture content of the lavender plant

Harvest moisture contents were determined by considering the maturity levels at each harvest period of the machine. The following equation was used to calculate the moisture content (Jarimopas et al., 2009).

$$\text{Percent}_{\text{moisture (wet.bases.)}} = (W_b - W_a)/\, W_b x100 \quad \text{(Eq.8)}$$

where,

Wb: the weight of lavender plant before drying,

Wa: the weight of lavender plant after drying.

3. Results and Discussion

The main operating principle of the machine is to position the lavender plant vertically using guiding arms, allowing for the cutting process. After cutting, the lavender harvesting machine bundles the product and leaves it on the field surface.

3.1. The cutting efficiency

To determine the cutting efficiency, the remaining products on the lavender cluster were weighed after the cutting process to obtain the total product weight. The ratio of the harvested products to the total products was calculated, and the results are presented in *Table 1*.

Table 1. Results of cutting efficiency trials

Cutting Efficiency (%)			
	Forward Speed (km h^{-1})		
Repeat	**3**	**5**	**8**
1	96.4	96.1	92.9
2	97.2	96.6	94.5
3	95.9	95.8	91.4
Avg.	96.5±0.66	96.2±0.40	92.9±1.55

At different machine forward speeds (3, 5 and 8 km h^{-1}), the cutting unit efficiency was found to be 96.5, 96.2 and 92.9%, respectively. The cutting loss values were calculated to be 3.5, 3.8 and 7.1, respectively. The average cutting efficiency value was calculated to be 95.2%. It was observed that the cutting losses were higher at the forward speed of 8 km h^{-1}. This indicates a negative correlation between machine speed and cutting efficiency. Similar trends have been reported in studies on other harvesting mechanisms. Higher forward speeds resulted in decreased operational efficiency due to reduced precision in the cutting process (Dong et al., 2011; Guo et al., 2021)

3.2. The binding efficiency

In the trials conducted to determine the binding efficiency, the ratio of the weight of the bundled products to the total products was calculated, and the results are presented in *Table 2*.

Table 2. Results of binding efficiency trials

Binding Efficiency (%)			
Forward Speed (km h^{-1})			
Repeat	**3**	**5**	**8**
1	69.9	65.6	58.3
2	75.6	68.6	62.3
3	73.9	71.3	66.6
Avg.	73.1±2.93	68.5±2.85	62.4±4.15

The binding unit efficiency was calculated at different machine forward speeds (3, 5 and 8 km h^{-1} as 73.1, 68.5 and 62.4%, respectively. Correspondingly, the binding loss values were calculated as 26.9, 31.5 and 37.6%. The average binding efficiency was determined to be 68.0%. It was observed that binding losses increased when the speed exceeded 5 km h^{-1}.

These findings align with the results from Dimitriadis (2005), who suggested that higher forward speeds negatively impact the efficiency of lavender harvesting machines due to product misalignment and increased cutting losses. Additionally, Muscalu et al. (2017) emphasized the importance of optimizing forward speed and mechanical design to enhance the performance of low-capacity harvesting equipment (Muscalu et al., 2017)

3.3. Machine performance and energy efficiency

The trials were conducted at three different forward speeds (3, 5, and 8 kmh^{-1}) and during three different harvest times (H1, H2, H3). For each harvest period, the moisture content of the lavender plants was determined to be 67%, 69%, and 74%, respectively.

In the preliminary trials, it was determined that the rotational speed of the shaft providing motion to the guiding chain-sprocket system of the harvesting unit should be 560 rpm at a forward speed of 5 km h^{-1}. If the rotational speed of the shaft is lower or higher than the specified value at 5 km h^{-1} forward speed, the products cannot be guided into a vertical position in front of the knife, resulting in an improper cutting process. These findings are consistent with the observations of Trendafilov and Delchev (2010), who reported that precise calibration of mechanical components is critical for achieving optimal harvesting efficiency.

The cutting unit knife speed, which is driven by the knife arm transmission, needs to be 1.9 m s^{-1}. The trials were conducted at this knife speed of 1.9 m s^{-1}.

With the prototype machine, at speeds of 3, 5 and 8 km h^{-1} for lavender plants, and at harvest moisture levels of H1: 67%, H2: 69%, and H3: 74%, the following values were determined: machine field capacity (ha h^{-1}), machine work capacity (kg h^{-1}), draft force (N), draft power (kW), and PTO power (kW) (*Table 3*).

The draft force values varied depending on crop and soil structure during the different harvesting periods. With increasing forward speed, an overall increase in draft force values was observed in all harvesting periods, but no significant differences were found (*Figure 7*). For harvest periods H1 and H2, the relationships between draft force and forward speeds of 3 and 5 km h^{-1} were not statistically significant. The lowest draft force value was obtained at a forward speed of 3 km h^{-1} as 1.020 N during the H1 harvest period when the crop moisture content was 67% w.b.

The results indicate that the lavender harvesting machine performs optimally at a forward speed of 5 km h-1, balancing cutting efficiency and binding performance. Higher speeds lead to increased losses, while lower speeds reduce field capacity. This aligns with findings from Balog and Brad (2024), who explored the integration of autonomous systems to optimize harvesting efficiency under varying field conditions.

Table 3. Harvest parameters for lavender plants

	Forward Speed (km h^{-1})	H1 (%67)	H2 (%69)	H3 (%74)
Field capacity (da h^{-1})	5	2.47c	2.47c	2.47c
	8	4.13b	4.13b	4.13b
	3	6.60a	6.60a	6.60a
	Avg.	4.40	4.40	4.4
Work capacity* (kg h^{-1})	3	1.086,8^{c}	1.235,0^{c}	1.432,6^{c}
	5	1.817,2^{b}	2.065,0^{b}	2.395,4^{b}
	8	2.904,0^{a}	3.300,0^{a}	3.828,0^{a}
	Avg	968.0	1,100.0	1,276.0
Draft Force** (N)	3	1.020b	1.050b	1.090c
	5	1.050b	1.070b	1.160b
	8	1.130a	1.250a	1.290a
	Avg	1026.7	1153.3	1180.0
Draft Power (N)	3	2.70c	3.15c	3.27c
	5	5.25b	5.80b	5.80b
	8	9.04a	10.00a	10.32a
	Avg	5.66	6.32	6.46
PTO Power (kW)	3	3	3.34c	3.39c
	5	5	3.85b	4.07b
	8	8	4.64a	4.64a
	3	Avg	3.94	4.03

* When calculating machine work capacity, the field yield was assumed to be 440, 500, and 580 kg da^{-1} for the H1, H2, and H3 harvest periods, respectively.
**The differences between the relationships determined for different forward speeds (3, 5, and 8 km h-1) in each harvest period were found to be statistically significant ($P<0.05$). For draft force values, no statistically significant difference was observed at forward speeds of 3 and 5 km h^{-1} during the H1 and H2 harvest periods

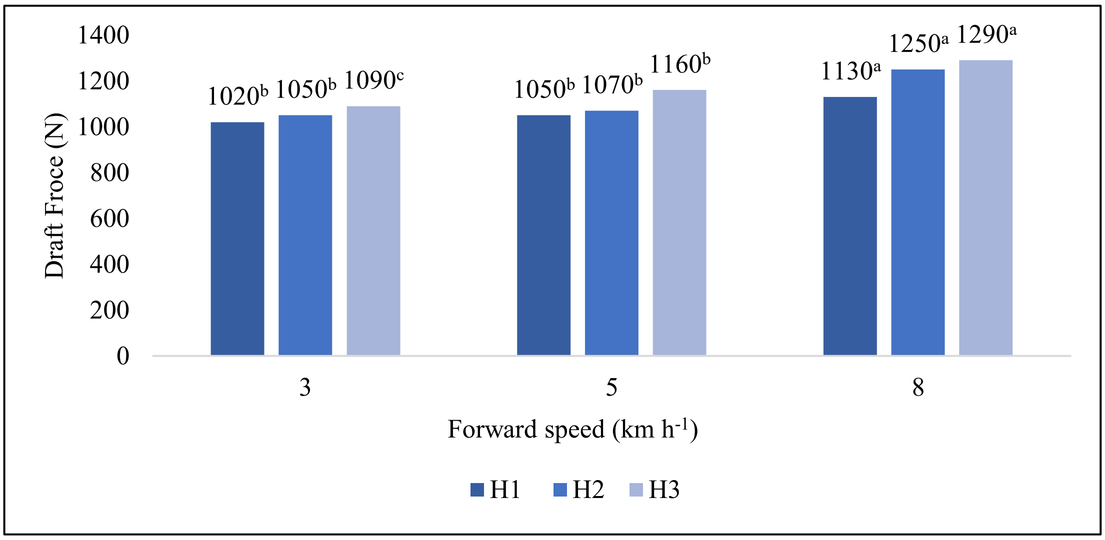


Figure 7. Draft force values (N) at different forward speeds (km h^{-1}) for H1 (%67 w.b.), H2 (%69 w.b.), and H3 (%74 w.b.) harvest periods

While there was a slight increase in draft power values over the different harvesting periods, the values changed significantly with forward speed, increasing as speed increased. At a forward speed of 5 km h^{-1}, the draft power values for harvest periods H2 and H3 were identical, both being 5.80 kW. However, at a forward speed of 8 km h^{-1} there was a significant increase in draft power. Draft power values of 9.04 kW, 10.00 kW and 10.32 kW were measured for H1, H2 and H3 harvesting periods respectively (*Figure 8*). The average draft power values at forward speeds of 3, 5 and 8 km h^{-1} were calculated to be 3.03 kW, 5.46 kW and 9.34 kW respectively.

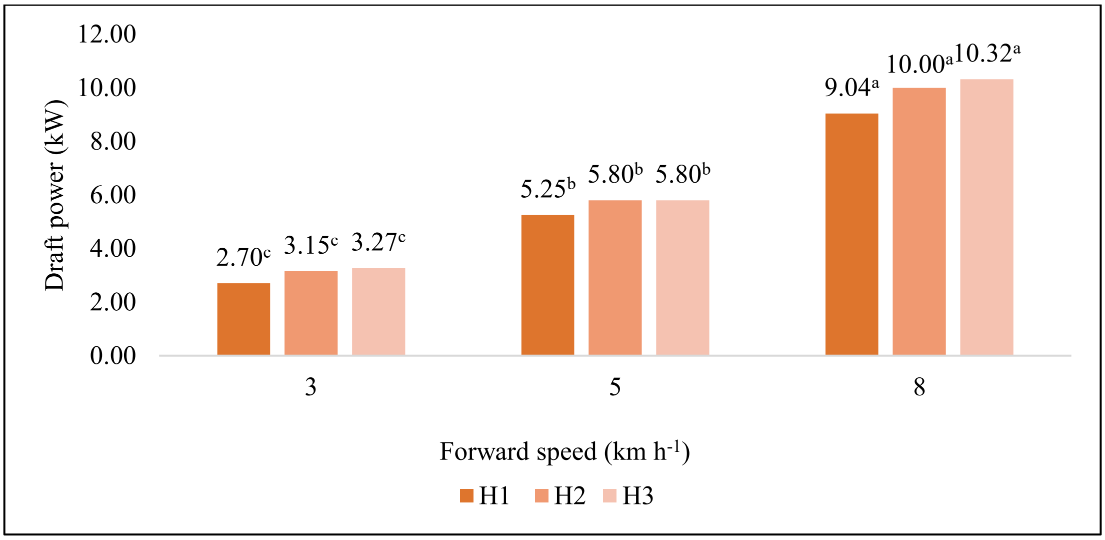


Figure 8. Draft power values (kW) at different forward speeds (km h^{-1}) for the H1 (%67 w.b.), H2 (%69 w.b.), and H3 (%74 w.b.) harvest periods

The PTO (power take-off) power values obtained during the different harvesting periods were relatively close to each other. However, an increase in PTO power was observed with forward speed increased. The highest PTO power value was recorded during harvest period H3 at a forward speed of 8 km h^{-1} as 4.69 kW (*Figure 9*). The average PTO power values were calculated to be 3.29 kW, 4.25 kW and 5.49 kW for the forward speeds of 3, 5, and 8 km h^{-1} respectively.

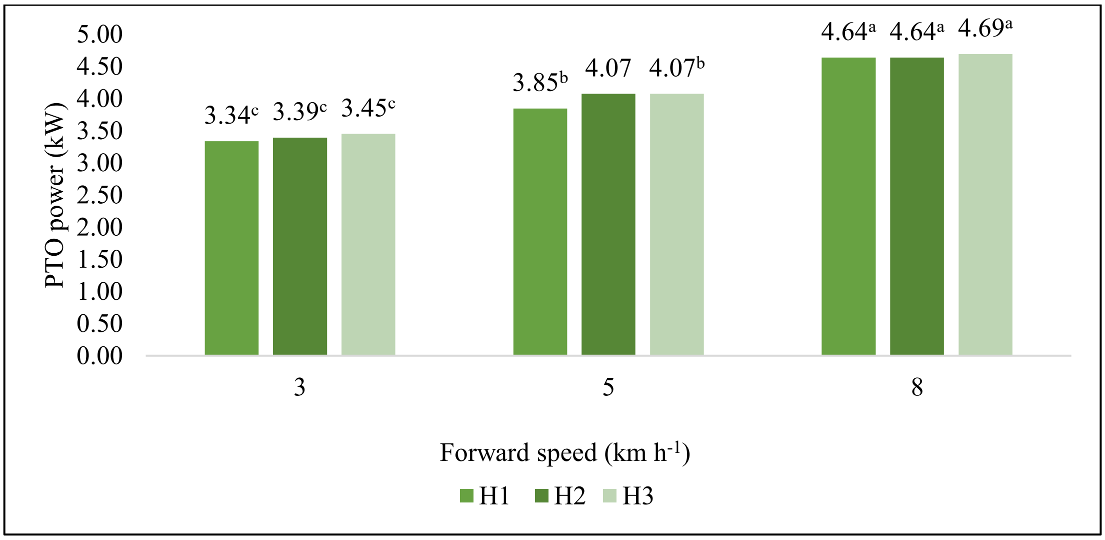


Figure 9. PTO power values (kW) at different forward speeds (km h^{-1}) for the H1 (%67 w.b.), H2 (%69 w.b.), and H3 (%74 w.b.) harvest periods

3.4. Volatile oil yield and harvest timing

In different harvesting periods (H1, H2, and H3), the volatile oil content of lavender plants, measured in milliliters using 50 g of dry flowers, was determined as 4.90, 4.81, and 4.43% respectively. Statistical analysis revealed a significant relationship between the harvesting periods (H1, H2, and H3) and the volatile oil content ($P<0.05$) (*Figure 10*).

Volatile oil yield is directly related to harvest timing. Higher yields were obtained at 67% and 69% moisture levels. These results are consistent with the optimal harvest timing for lavender determined in studies conducted in Bulgaria (Stanev et al., 2016).

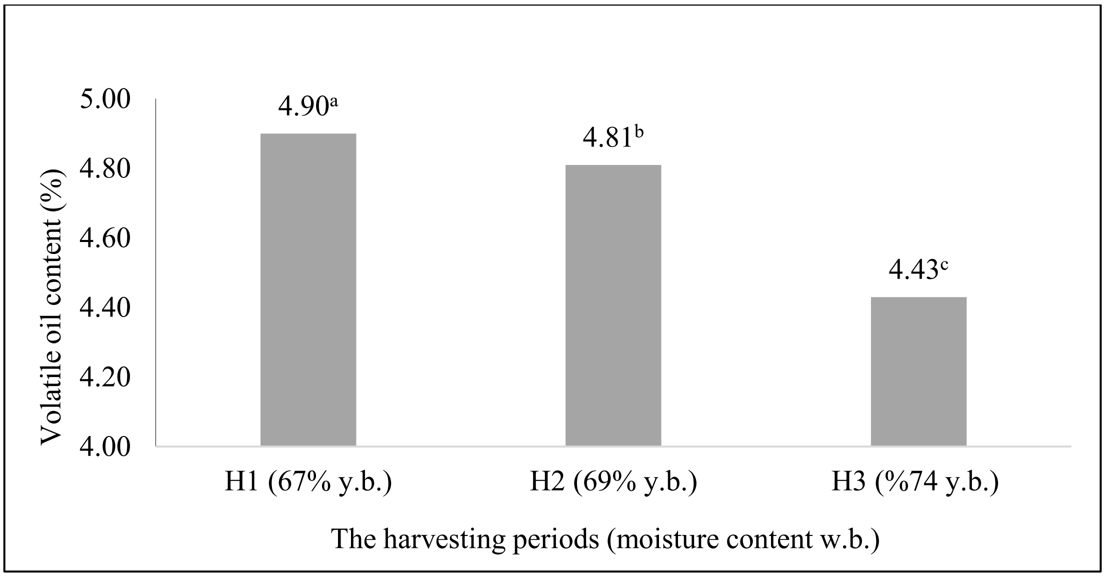


Figure 10. The volatile oil ratios obtained at different harvest times

This study represents a significant step towards the development of local lavender harvesting machines. There is limited research on the mechanization of lavender farming in Turkey, and increasing studies in this field is essential (Yılmaz and Gökduman, 2021). Furthermore, to minimize binding losses, automated systems like those developed by Neo Makine (2024) could be integrated into future prototypes.

The findings underline the importance of optimizing both mechanical design and operational parameters to enhance the efficiency and sustainability of lavender harvesting. Future research should focus on testing alternative binding mechanisms and exploring the integration of advanced automation technologies to further improve machine performance.

4. Conclusions

In the trials conducted, it was found that the lavender harvester was capable of harvesting at the desired height in any lavender field planted with row spacings of 1500 mm or more under Turkish terrain conditions. However, it was decided that alternative systems for the binding unit should be investigated and their efficiency improved.

Based on the results of the trials, it was concluded that lavender harvesting should be carried out at a forward speed of 5 km h^{-1}. At lower speeds, both machine output and field capacity are reduced, while at higher speeds the increased product density makes it difficult to cut and transport the plants vertically, reducing machine performance.

The speed of the drive shaft for the chain transmission of the cutting unit must be 560 rpm at a forward speed of 5 km h^{-1} to ensure that the guide arms can guide the lavender plants to the cutting knives in an upright position. In order to cut the lavender stems without damaging them, the knife speed must be 1.9 m s^{-1}. The experiments were carried out at this knife speed.

The cutting efficiency of the prototype machine was calculated to be an average of 95.2%. The binding efficiency of the machine was found to be 68.0%. The results of the laboratory and field trials, together with observations, indicate that harvesting and transport of the crop without using the binding unit, via a conveyor belt to a wagon or platform, can be achieved with high efficiency. However, the use of the bundle binding unit resulted in increased binding losses due to product density, deformation of the binding material, and blockages in the stretch binding arm. Therefore, alternative binding systems need to be tested and the performance of the machine improved to work more effectively with the binding process.

Harvesting is recommended when the moisture content of the lavender is 67% and 69% y.b. During these periods, the product yields higher essential oil content. In addition, from an agricultural mechanization point of view, harvesting when the moisture content is lower results in lower power requirements at the recommended forward speed of 5 km h^{-1}, the average draft power and PTO power requirements were determined to be 5.46 kW and 4.25 kW, respectively, with a total machine power requirement of 9.71 kW.

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Conflicts of Interest

There is no conflict of interest between the article authors.

Authorship Contribution Statement

Concept: Gökduman, M. E., Yılmaz, D.; Design: Gökduman, M. E., Yılmaz, D.; Data Collection or Processing: Gökduman, M. E., Yılmaz, D.; Statistical Analyses: Gökduman, M. E.; Literature Search: Gökduman, M. E.; Writing, Review and Editing: Gökduman, M. E., Yılmaz, D.

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