Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Work Efficiency, Labor Requirement and Harvesting Costs of Mechanical and Pneumatic Hazelnut Harvesters

Ali Tekgüler

atekgul@omu.edu.tr

Ondokuz Mayıs University

Taner Yıldız

Ondokuz Mayıs University

Research Article

Keywords: Work efficiency, Cost, Mechanical harvest, Labour requirement, Hazelnut

Posted Date: September 24th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10669849/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Work Efficiency, Labor Requirement and Harvesting Costs of Mechanical and Pneumatic Hazelnut Harvesters

Ali Tekgüler*

Program of Agricultural Machinery and Technologies, Department of Machinery and Metal Technologies, Vocational School of Samsun, University of Ondokuz Mayıs, İlkadım, Samsun, 55100, TÜRKİYE

*Corresponding author: atekgul@omu.edu.tr

https://orcid.org/0000-0002-0273-5014

Taner Yıldız

Department of Agricultural Machinery and Technologies Engineering, Faculty of Agriculture, University of Ondokuz Mayıs, Atakum, Samsun, 55139, TÜRKİYE

tyildiz@omu.edu.tr

https://orcid.org/0000-0002-4774-6534

Abstract: Türkiye leads global hazelnut production and exports, yet extremely low mechanization levels drastically inflate labor demands during harvest. Because harvesting accounts for nearly half of total production expenses, adopting specialized harvesters is essential for cost reduction. Unlike other producer nations where operations from desuckering to field cleaning are almost fully mechanized, Türkiye's chain remains largely restricted to husking. For over 35 years, pneumatic and mechanical harvesters have been studied, leading to local production alongside imports for flat or near-flat terrains. In this study, conducted in Çarşamba town, Samsun Province, aimed the evaluate labor requirement, work efficiency, and harvesting costs of domestically produced pneumatic and mechanical harvesters. For the double-acting pneumatic harvester, 0.7–0.8 meter wide windrows were created with a back blower before collecting the nuts. With the mechanical harvester, nuts between branches were swept directly into the machine's impact zone using a blower, bypassing the windrowing step. Results showed the double-acting pneumatic harvester achieved a product work efficiency of 0.203 th^{-1}, a labor requirement of 4.549 hda^{-1}, working efficiency per unit area of 0.219 dah^{-1}, and a harvesting efficiency of 99.86%. In comparison, the mechanical harvester yielded a product work efficiency of 0.195 th^{-1}, labor requirement of 1.596 hda^{-1}, working efficiency per unit area of 0.627 dah^{-1}, and harvesting efficiency of 97.55%. Harvesting costs were calculated at 110.30 $\$da^{-1}$ for the traditional manual method, 76.28 $\$da^{-1}$ for the pneumatic harvester, and 18.90 $\$da^{-1}$ for the mechanical harvester, respectively. Ultimately, mechanical harvesting substantially reduces overall labor demands and expenditures while increasing area efficiency.

Keywords: Work efficiency, Cost, Mechanical harvest, Labour requirement, Hazelnut

Introduction

Türkiye is the leading country in terms of hazelnut production and export worldwide. It is an important issue for Türkiye, which also grows the highest quality hazelnuts among hazelnut producing countries, to reduce the cost of hazelnut production in order to maintain this position. One of the most important problems in hazelnut farming in our country is the inadequate use of mechanization. Approximately 50% of total production costs are attributed to harvesting operations. Hazelnut harvesting is generally done by manually in Türkiye. In the Black Sea Region, hazelnut is cultivated on average in areas with a 40% slope, and it is considered quite difficult to harvesters in these areas. However, in recent years, it will be beneficial to reduce costs and to have a profitable production by harvesting especially in flat and nearly flat areas, which constitute almost half of these areas.

Hazelnut producers in Türkiye harvest traditionally, that is, early by hand, for various reasons. The most important reasons for early harvesting can be stated as; especially in recent years, due to the difficulty of finding human labor, it is easier to provide human labor before entering the period of intensive harvest and labor demand, not extending the harvest-threshing and drying processes until the rainy periods, and adopting the most appropriate method of picking the fruits from the branches in the early period before they fall to the ground in very sloping areas. On the other hand, hazelnut orchards in our country are established with many mixed varieties. Even when harvesting is started at the optimum time for commonly grown varieties, it is done too early for some other varieties. One of the conditions for obtaining the highest fruit quality and yield in hazelnuts is to harvest at the appropriate time.

For the last 30-35 years, research has been carried out on developing and implementing systems and harvesters suitable for our country's conditions in order to minimize the intensive labor requirement and harvesting costs of mechanical harvesting of hazelnuts, and studies on this subject are ongoing. In countries that produce hazelnuts economically in the international market, mechanical harvesting methods have been developed according to the topography of the land, planting technique and the characteristics of the hazelnut variety. For this reason, different mechanical harvesting technologies are applied in different production regions of the world. However, in Türkiye, which meets a large part of the world's hazelnut production, hazelnuts are still largely collected traditionally.

In Türkiye, mechanical harvesting studies started with pneumatic pick-up unit harvester trials, the design and manufacturing of which was carried out by Beyhan (1992). In the studies, it was determined that power consumption was high and work performance was low and that the use of aspiration harvesters required two workers to manage the hoses and one person to drive the vehicle. In addition, it was emphasized that ground preparation should be done to a great extent in the study with aspiration harvesters. As a result of the trials, in a orchard yield of 226.8 $kgda^{-1}$, work performance was determined as 28.48 kg human labor power in hours per hectare ($HLPhda^{-1}$) (as hazelnut grains), harvest efficiency as 95.13% and field work performance as 0.396 dah^{-1}. On the other hand, all these operations can be done by one person with machines with mechanical pick-up units. To increase harvest efficiency and labor productivity, minimize yield losses, scan wider areas, reduce dust problems, achieve good results on rough ground, and reduce power requirements, mechanical pick-up unit harvesters have been developed (Ghiotti 1989; Biondi et al. 1992; Yıldız 2000). In a study with a hazelnut harvester with a mechanical pick-up unit designed in accordance with Türkiye conditions, it was determined that when working at 225 $kgda^{-1}$ orchard yield, 3.2 kmh^{-1} ground speed and 430 min^{-1} pick-up unit revolution per minute; product work efficiency was 100.29 kgh^{-1} as dried hazelnuts for milling (grain basis), harvest efficiency was 91.66% and working efficiency per unit area (WPA) was 1-1.5 dah^{-1} depending on orchard yield. As a result, it was emphasized that the machine significantly reduced labor requirement in flat and nearly flat areas where it could work without tipping over (Yıldız 2000).

Although Italian agricultural machinery manufacturers have been trying to enter the Türkiye market for years, they have not been efficiencyful (by bringing machinery to Türkiye and conducting demonstrative trials in farmers' orchards) due to the fact that the machinery are not suitable for our country. In recent years, hazelnut harvesters operating according to different principles have been manufactured by local manufacturers and sold to farmers. These are divided into two groups: mechanical pick-up unit and pneumatic pick-up unit harvesters. Today, the harvesting process has been completely mechanized in some hazelnut producing countries other than Türkiye. For example, in Italy, since the 1980s, mechanized harvesting has almost replaced manual harvesting and has continuously developed. In recent years, self-propelled hazelnut harvesters, especially together with sweepers, have started to be used to a large extent. In addition, hazelnuts collected using portable blowers on backs are also

collected with mechanically effective machines (Monarca 1995; Franco and Monarca 2001; Tombesi 2005; Zimbalatti 2012).

This study was conducted to evaluate two different hazelnut harvesters, one with a mechanical and the other with a pneumatic pick-up unit, which were designed and manufactured by local manufacturers in recent years and have started to be used in our region, in terms of labor requirements, work efficiency and harvest costs in a flat and row type hazelnut orchard.

Materials and Methods

Materials

Experimental Hazelnut Orchard

The trials were carried out in a farmer's orchard in Yukarı Dikencik village, Çarşamba District of Samsun Province (Fig. 1).

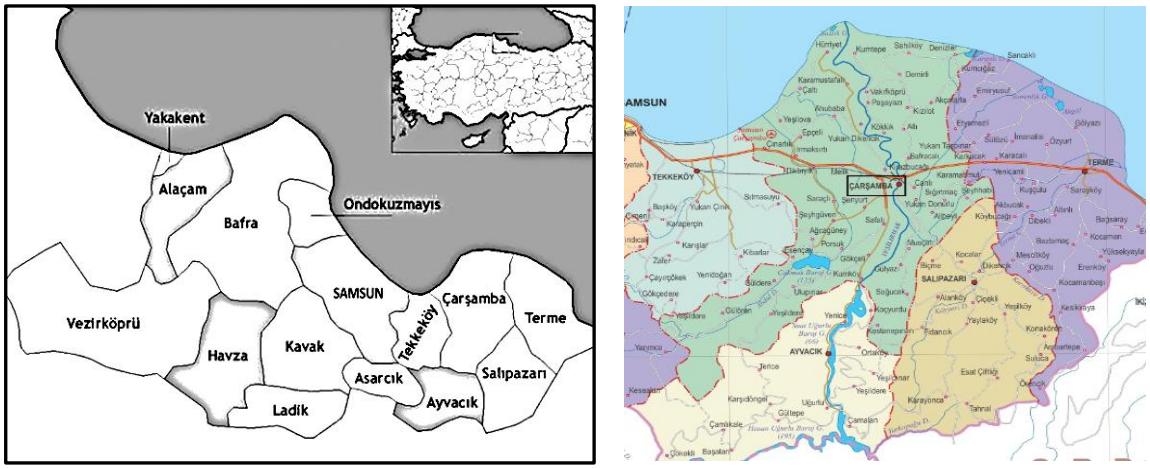


Fig. 1 Map of research area

The orchard is 44.22 da in size and has a row type planting system. Although the Palaz variety hazelnuts are predominantly found in the orchard, there are also varieties such as Tombul, Yerli, Hanım, Acı, Kalınkara, Sivri and Ham hazelnut. In the Palaz hazelnut variety, up to 70% shedding is observed towards the end of harvest, 90% shedding in local hazelnut, and mostly graining is observed in Yerli and Hanım hazelnuts. The characteristic features of the orchard used as a trial area are given in Table 1.

Table 1 Some characteristics of hazelnut orchard

Establishment age of the orchard (years)	10
Planting system	Row type
Distance between rows (m)	6
Orchard length (m)	402
Orchard width (m)	110
Number of rows	67
Total area (da)	44.22
Orchard yield (kg da^{-1})	250-300
Slope (%)	1-2

Measuring instruments used in the experiments

A 750 g capacity electronic scale with 0.001 g precision was used to weigh hazelnuts and other foreign substances in the experiments, a CASIO brand stopwatch was used for time measurements, and an orchard rake was used to turn the grains and hazelnuts that fell on the ground into windrows.

Pneumatic pick-up unit hazelnut harvester used in the trials

This machine used in the trials is a tractor-drawn type with a minimum power of 18 kW. It consists of 5 main units: aspirator, separator, discharger, suction mouth and transmission hose. It gets its movement from the tail shaft with the help of a shaft. Hazelnuts, leaves, small branches, stones and dust collected from the ground with the suction pipe come to the passive separator. The mixture discharged from the separator passes through the air flow created by the fan, while light materials such as leaves etc. are removed. The cleaned hazelnuts pass to the air conveyor fed by the radial fan and are bagged here. A New Holland brand tractor with a power of 37 kW (50 HP) was used in the trials. Some other technical features of the hazelnut harvester are given in Table 2.

Table 2 Some technical features of pneumatic pick-up unit hazelnut harvester

Transmission hose diameter and length (mm)	120 x 25000 (Two pieces)
Fan type	Radial
Air delivery (m^3h^{-1})	8500
Air speed (ms^{-1})	100
Fan type	Backward-facing blade
Overall width x Overall length x Overall height (mm)	1700 x 3100 x 1850
Net weight (kg)	625

Mechanical pick-up unit hazelnut harvester used in the trials

This machine used in the trials is a self-propelled machine equipped with a 4.8 kW motor. It consists of 4 main units: pick-up unit, separation system, storage and power. Some technical features of the mechanical hazelnut harvester are given in Table 3.

Table 3 Some technical features of the mechanical pick-up unit hazelnut harvester

Motor power (kW)	4.8
Total working width (mm)	1300
Overall length (mm)x Overall height (mm)x Overall width (mm)	3500x1500x1650
Brake system	Hydraulic

Methods

Harvesting methods

The weather was clear and sunny on the date of the study, and there was no rain. The air temperature was 28 $^{\circ}$C and the relative humidity was 67%. Three different harvesting methods were applied in the experiments. The harvesting methods are as follows:

Mechanical Method

Blowing the hazelnuts in the rows to the affected area with a blower without making a windrow in the orchard with a row type planting system + pick up with a mechanical unit machine.

Pneumatic Method

In the orchard with a row type planting system, making windrow with a blower + orchard rake + pick up with a pneumatic unit machine.

Traditional Method

Hand harvesting from the orchard ground (It was evaluated as the control group and was evaluated as collecting only the hazelnuts from the ground and in the shrubs without using any harvesting aids).

Measurements and Evaluation

Time measurements

The processes were divided into three work phases as given below and the total working time for each process were formed from three time sections in the experiments. The time sections were arranged as hda^{-1} in row type planting system with pneumatic and mechanical pick-up unit hazelnut harvesters (Kadayıfçılar and Dinçer 1972; Beyhan and Pınar 1996; Yıldız 2000; Yıldız and Tekgüler 2012). Making windrows with a blower is given in Fig. 2; and working with mechanical and pneumatic pick-up unit harvesters is given in Fig. 3 and Fig. 4.




Fig. 2 Harvesting the hazelnuts between the rows with a blower and making a windrow




Fig. 3 Working with hazelnut harvester with pneumatic pick-up unit




Fig. 4 Working with hazelnut harvester with mechanical pick-up unit

Time Sections in Working with Traditional, Pneumatic and Mechanical Pick up Unit Harvesters

Time sections are divided into three main sections.

These are;

I. Basic Time (BT) (hda^{-1}): Harvesting time from the place where the windrow is made/not made.

$BT = t_{BT1} + t_{BT2} + t_{BT3}$

t_{BT1}: Time to collect from the ground manually

t_{BT2}: Time to collect remaining hazelnuts within rows

t_{BT3}: Time to collect remainder from the branch by hand

II. Auxiliary Time (AT) (hda^{-1}): The necessary time spent to combine various time sections (tAT). Auxiliary time is also divided into subgroups among themselves (Yıldız 2000).

$$AT = tAT1 + tAT2 + tAT3 + tAT4 + tAT5 + tAT6 + tAT7 + tAT8 + tAT9 \quad (1)$$

Where;

t_{AT1}: Turning time on the end of the plots;

t_{AT2}: Time to passing from windrow to windrow;

t_{AT3}: Fuel supply time;

t_{AT4}: Bag tying + bag removal time + transportation to trailer;

t_{AT5}: Time of windrowing with blower;

t_{AT6}: Time of windrowing with rake;
t_{AT7}: Resting time + break time;
t_{AT8}: Time of sweeping with blower;
t_{AT9}: Time of passing between the rows.

III. Unavoidable Time Loss (UTL) (hda^{-1})

Calculation of labor requirement and work efficiency

To determine labor requirements and work efficiency, we used the arithmetic means of the time segments measured for each process (Beyhan and Pınar 1996). It is determined as the percentage of the BT obtained by adding the BT and AT (Caran 1994; Beyhan and Pınar 1996; Yıldız 2000). In calculating labor requirements and work efficiencies, arithmetic averages of the findings determined by measurements for time sections related to each process were used (Beyhan and Pınar 1996). In determining the Work Efficiencies, Effective Working Time (EWT) was taken into account. In order to determine the EWT, the Principal Time (PT) consisting of the sum of the BT and AT was first calculated.

$$PT = BT + AT \ (hda^{-1}) \quad (2)$$

EWT was calculated from the following equation.

$$EWT = BT + AT + UTL \ (hda^{-1}) \quad (3)$$

UTL was determined as a percentage of the PT obtained by adding BT and AT (Caran 1994, Beyhan and Pınar 1996; Yıldız 2000).

$$UTL = \frac{P}{100} PT \quad (4)$$

Here, P is a multiplication factor that varies according to the hazelnut harvester used and labor power. In this study, P was taken as 1 for labor power and 6 for machine power (Caran 1994; Beyhan 1996; Yıldız and Tekgüler 2012). The WPA in the study with the hazelnut harvester was determined with the following equation, linked to the EWT.

$$WPA = \frac{1}{EWT} \ (hda^{-1}) \quad (5)$$

The utilization coefficient (UC_z) was calculated from the following equation using total time.

$$UC_z = \frac{BT}{EWT} 100 \ (\%) \quad (6)$$

The trials took place on three 120 m long hazelnut rows in a linear orchard, where each row served as a repeat. Time segments were measured by starting a stopwatch when the laborer began working on a row and stopping it when they reached the end. The experiments were carried out in the hazelnut rows selected in the row type hazelnut orchard, with 20 replications. In order to take time measurements, the stopwatch was started at the beginning of the study and ended at the end of the row (Bolli and Scotton 1987; Zimbalatti et al. 2012).

Determination of harvesting costs

In the study, machine usage costs were classified under two groups as fixed costs and variable costs (Dinçer 1976; Kadayıfçılar and Erdoğan 1988; Yıldız 2000). These are given in Table 4. Fixed costs are not dependent on the use of tools and machines, and these costs should be calculated even if the machine is not working. Annual fixed costs vary depending on the machine, but on average they are 22-28% of the purchase price of the machine. This value was taken as 25% for hazelnut harvester. Variable costs depend on the working hours of the tools and machines in a year (Keskin and Erdoğan 1992).

Fuel costs were calculated from the hourly diesel consumption measured for the machines. The amount of fuel consumed was identified from the full tank method for three repeats. The fuel cost per liter was taken as 0.81 $\$L^{-1}$ while the oil cost per liter was 5.29 $\$L^{-1}$. To determine human labor costs, we used the standard regional wage for a 10 hour work shift in the hazelnut harvest, assuming that all manual and mechanical operations were conducted by one person. In calculating personnel costs the 2021 harvest fee (daily the worker wage) was taken as 17.63 \$ day^{-1} (1.763 $\$h^{-1}$). Repair and maintenance costs were not taken into account. The working hours of the hazelnut hervester during the year were taken as 100 hours, assuming a 10 day harvest period and 10 hours of work per day (Beyhan 1992). The purchase price of the harvester with a mechanical picking unit for 2021 is 4700.35 \$ and the purchase price of the harvester with a pneumatic picking unit is 5287.89 \$. The price of 1 kg of dried hazelnuts for milling (grain basis) in the 2021 harvest season was taken as 2.761 $\$kg^{-1}$.

Table 4 Parameters considered for economic analysis

Cost item	Symbol	Source
Fixed costs		
Interest	***(f)***	$\frac{(\text{Machinery Value (\$)} + \text{Salvage Value (\$)})}{2}$ x Interest rate (%)
Depreciation	**(a)**	$\frac{(\text{Machinery Value (\$)} - \text{Salvage Value (\$)})}{\text{Economical Life of Machinery (year)}}$
Insurance	**(I)**	Ministry of Treasury and Finance
Tax	**(T)**	Ministry of Treasury and Finance
Space cost	**(SC)**	Area occupied by the machine (m^2) Space (m^2) x Space price per unit ($\$m^{-2}$) or (0,01~0,03)
Total fixed costs per year ($\$year^{-1}$)	$\mathbf{TFC_{py}}$	*f*+a+I+T+SC
Total fixed costs per hour ($\$h^{-1}$)	$\mathbf{TFC_{ph}}$	TFC_{ph} / Average annual machine use ($hyear^{-1}$)
Variable costs		
Fuel consumption cost ($\$h^{-1}$)*	**(FC)**	Fuel consumption per hour (Lh^{-1}) x Fuel price per liter ($\$L^{-1}$)
Oil consumption cost ($\$h^{-1}$)	**(OC)**	Oil consumption per hour (Lh^{-1}) x Oil price per liter $\$L^{-1}$)
Repair-Maintenance ($\$h^{-1}$)	**RM**	Repair-maintenance per year ($hyear^{-1}$) x Repair-maintenance price per hour ($\$h^{-1}$)
Labour cost ($\$h^{-1}$)	**(WLC)**	Number of worker x Average wage per hour ($\$h^{-1}$)
Total variable costs per year ($\$year^{-1}$)	$\mathbf{TVC_{py}}$	FC+OC+RM+WLC
Total variable costs per hour ($\$h^{-1}$)	$\mathbf{TVC_{ph}}$	TFC_{py} / Average annual machine use
Total harvesting costs per hour ($\$h^{-1}$)	**THC**	TFC_{ph} + TVC_{ph}
Harvesting cost per kg in Shell ($\$kg^{-1}$)	**HCkg**	THC / Harvesting year per hour (kgh^{-1})
Harvesting cost per kg in Shell ($\$da^{-1}$)	**HCda**	HCkg x Harvesting year per decare ($kgda^{-1}$)

*: The amount of fuel consumed was identified from the full tank method for three repeats.

Determination of WPA

To determine the area harvest efficiencies of hazelnut harvesters, 1.3 m × 100 m, approximately 130 m^2 trial plots were created for the mechanical harvester; and 0.7 m × 100 m, 70 m^2 plots were created for the pneumatic harvester. For this purpose, hazelnuts with hulls and kernels were laid out on the plots as if they were naturally spilled. The spilled hazelnuts were collected by the harvester. Harvesting efficiency was calculated by proportioning the weight of hazelnuts collected by the harvester to the weight of hazelnuts spilled on the plot. The values in traditional harvest were determined by collecting the hazelnuts with hulls and kernels in 2.25 m^2 plots measuring 1.5 m × 1.5 m by the same person and measuring the time. The obtained values were converted to standard parcel (da).

Determination of Product Work Efficiency (PWE)

For the mechanical pick-up unit harvester, the product was collected with the harvester in 130 m^2 parcels and for the pneumatic pick-up unit harvester, in 70 m^2 parcels with three repetitions. The time measurements for each harvest trials were recorded with a stopwatch. The following equation was used to determine the Product Work Efficiency.

$$PWE = \frac{HP}{T} \quad (7)$$

PWE: Product Work Efficiency (th^{-1})
HP: Harvested Product (t)
T: Harvesting Time (h)

Determination of moisture contents

Just as the maturity periods of hazelnuts vary according to the varieties, hazelnut fruits of the same variety do not ripen at the same time. This causes the moisture contents of the same variety of hazelnut fruits to be different during the harvest period. The sample grains taken were dried by chopping the shell + kernel, shell, kernel and husk and 10 samples each. The samples were placed in containers and the drying method was applied in the oven

at 103 ˚C (±2 ˚C) until they reached a constant weight. After the samples taken from the cabinet were cooled in the desiccator, their dry tare weights were determined. The moisture content was determined with the help of the equation given below (Ayık 1997).

$$\text{Moisture Content (\%)} = \frac{w_0 - w}{w_o} 100 \quad (8)$$

In the equation;

W_0: Product's wet weight (g),

W: Product's dry weight (g).

The final weights of hazelnuts with determined moisture content at the moisture levels in question were calculated with the equation given below (Beyhan 1996).

$$Gs = \frac{Gb\,(100 - \emptyset b)}{(100 - \emptyset s)} \quad (9)$$

G_s: Product's weight in dried form (kg),

G_b: Product's initial weight in wet form (kg),

$Ø_b$: Product's initial moisture content (%),

$Ø_s$: Final moisture content of dried product (%).

Comparative evaluation of the efficiency of hazelnut harvesters (Data Envelopment Analysis, DEA)

The efficiency of the hazelnut harvesters examined in the study was estimated by data envelopment analysis (DEA). DEA was preferred because it requires less data, allows working with small sample sizes, and does not require information about the functional form (Coelli et al. 2005). An input-oriented approach was used in the creation of the efficiency model and the estimate was made under the assumption of constant returns to scale. A 1-output and 2-input efficiency model was created in the study. Work efficiency is the output of the efficiency model. Labor requirement and harvesting cost are the inputs of the efficiency model. The measurements made and the data obtained for the harvesters examined within the scope of the study were expressed with an input matrix (X) in the size of KxN and an output matrix (Y) in the size of MxN. The technical efficiency for the harvesters examined was obtained by solving the following linear programming model:

$$Minimum_{\theta,\lambda}\ \theta$$

Limitations $-y_i + Y\lambda \geq 0$

$$\theta x_i - X\lambda \geq 0$$

$$\lambda \geq 0$$

In the equation, θ represents the technical efficiency score that takes values between 0 and 1 and λ represents the vector of Nx1 dimension that represents a linear combination of the enterprises examined. When the technical efficiency score is 1, the harvester that takes this value is considered fully efficient. A technical efficiency score of 0 indicates that it is not technically efficient.

Statistical Analysis

Before analysis, all data collected on two sampling days for normality and homogeneity were screened using the Kolmogorov-Smirnov test and Levene's test, respectively ($P>0.05$). Based on Duncan's multiple range test, the mean differences were deemed significant when $P<0.05$. The EWT, WPA, harvesting efficiency and PWE transformed to their corresponding angles' arcsin were determined by the Skewness and Kurtosis coefficients (±1.96); however, their actual values are presented. All statistical analyses were conducted using SPSS Software (Version 21.0, SPSS, Chicago, IL, USA).

Results

Results on the **measured values of BT, AT and calculated values of PT and EWT for** hazelnuts **harvested by mechanical, pneumatic, and traditional methods**

The values measured in this study were scaled to a standard one decare plot to calculate labor requirements and work efficiencies (Yıldız, 2000). Accordingly; the values of the BT, AT measured for hazelnut harvested with mechanical, pneumatic and traditional methods and the values of the calculated PT were arranged according to different methods and are presented in Table 5. In addition, a comparison of the EWT and WPA (n=20) values calculated from the PT and UTL values is given in Table 5.

Table 5 Measured values of BT, AT and calculated values of PT and EWT for hazelnut harvested by mechanical, pneumatic and traditional methods

Time sections	Harvesting Methods		
Standart BT (hda^{-1})	Mechanical	Pneumatic	Traditional
tBT_1	1.100	2.950	11.580
tBT_2	-	-	0.810
tBT_3	-	-	4.770
$\sum$BT (hda^{-1})	1.100	2.950	17.160
Standart AT (hda^{-1})			
tAT_1	0.038	-	-
tAT_2	-	0.024	-
tAT_3	0.006	0.005	-
tAT_4	0.080	0.080	0.990
tAT_5	-	0.407	-
tAT_6	-	0.790	-
tAT_7	0.036	0.036	0.036
tAT_8	0.210	-	-
tAT_9	0.036	-	-
($\sum$AT) (hda^{-1})	0.406	1.342	1.026
Standart PT (hda^{-1})	1.506	4.292	18.186
UTL (hda^{-1})	0.090	0.257	0.182
EWT (hda^{-1})	1.596	4.549	18.368
WPA (dah^{-1})	0.627	0.220	0.054
UC_z (%)	68.92	64.85	93.42

As seen from Table 5, when compared to traditional hazelnut harvest, auxiliary times were at the lowest level in harvest trials carried out with the mechanical collection unit machine, while EWT were at the highest level. Time utilization coefficients were found to be higher in the traditional method, followed by the mechanical and pneumatic pickup unit harvesters, respectively. The low coefficients in both harvesters were due to non-productive time periods. These values can be improved if better planning is made. When the statistical analyses given in Table 6 are examined, the EWT values obtained in all three methods are found to be significantly different from each other. The lowest value was obtained to mechanical pick-up unit harvester. The comparison of methods in terms of effectiveness according to the data envelopment method is given in Table 6.

Table 6 EWT and WPA (n=20, mean ± SE) values calculated from PT and UTL values for hazelnut harvesting with mechanical, pneumatic and traditional methods

	Mechanical	Pneumatic	Traditional	P-value
PT (hda^{-1})	1.506	4.292	18.186	
UTL (hda^{-1})	0.090	0.257	0.182	
EWT (hda^{-1})	$1.596^{c} \pm 0.192$	$4.549^{b} \pm 0.438$	$18.368^{a} \pm 0.897$	<0.001
WPA (dah^{-1})	$0.627^{a} \pm 0.411$	$2.220^{b} \pm 0.486$	$0.054^{c} \pm 0.006$	<0.001
Harvesting efficiency (%)	$97.55^{c} \pm 0.86$	$99.33^{b} \pm 0.49$	100.00^{a}	
PWE (kgh^{-1}) Husky	$195.37^{a} \pm 23.88$	$203.269^{a} \pm 8.03$	$10.374^{b} \pm 0.47$	<0.001
PWE (kgh^{-1}) Dried hazelnuts for milling (kgh^{-1})	65.123	67.756	3.458	
Harvesting cost ($\$da^{-1}$)	18.90	76.28	110.30	

Reslts on comparison of methods in terms of effectiveness according to the DEA method

The DEA results obtained according to Table 7 show that the technical efficiency coefficient is 1 for the mechanical harvester, 0.365 for the pneumatic harvester and 0.009 for the traditional harvesting. According to the efficiency model results, it is possible to reduce inputs by 63.5% without any decrease in product throughput in hazelnut harvest with a pneumatic harvester. It was determined that the labor requirement which is 4.549 hda^{-1} can be reduced to 1.661 hda^{-1} in the pneumatic method; and harvest costs can be reduced from 76.18 $\$da^{-1}$ to 19.621

da^{-1}. On the other hand, there is a quite high level of input waste in harvest with the traditional method. In the traditional method, the labor requirement which is 18.368 hda^{-1} can be reduced to 0.085 hda^{-1} without any decrease in product throughput. It is possible to reduce harvest costs from 110.164 $\$da^{-1}$ to 1.001 $\$da^{-1}$.

Table 7 Comparison of methods in terms of effectiveness

Harvesting Methods	Efficiency Score	PWE (kgh^{-1})	Labor requirement (hda^{-1})		Harvesting cost ($\$da^{-1}$)	
			Current Situation	Expected Situation	Current Situation	Expected Situation
Mechanical	1.000	65.123	1.596	1.596	18.90±2.22	18.90±2.22
Pneumatic	0.365	67.756	4.549	1.661	76.18±8.96	20,615±2,31
Traditional	0.009	3.458	18.368	0.085	110.16±12.96	1.001±0.118

In addition, when compared to the traditional harvesting method, a saving of 91.304 $ per decare can be achieved in the harvesting process with the mechanical pick-up unit harvester, and 33.983 $ in the harvesting process with the pneumatic pick-up unit harvester. The annual saving amount in the harvest season was 5724.676 $\$da^{-1}$ and 744.183 $\$da^{-1}$, respectively. When the payback period is evaluated according to the payback period method, the mechanical pick-up unit harvester will be able to amortize itself in 40000/48717=0.82 years, while the pneumatic pick-up unit harvester will be able to amortize itself in 45000/6333=7.1 years. In the evaluation made according to the net present value method, it was revealed that if the economic useful life of the harvesters is taken as 8 years and the annual interest rate is 10%, the use of the mechanical pick-up unit harvester present value of cash flows as +25840.188 $ is more profitable than the pneumatic pick-up unit harvester present value of cash flows as +1319.624 $.

Conclusions

The results obtained have shown that; in the experiments conducted in mechanical, pneumatic and traditional harvesting methods under the same orchard conditions, the use of mechanical pick-up unit harvesters has yielded more positive results in terms of EWT, WPA and harvest costs compared to other methods. At the same time, more ergonomically comfortable working conditions have been obtained with the mechanical harvester. Therefore, working with mechanical pick-up unit harvesters will be beneficial both economically and agro-technically. Thus, the decrease in harvest costs depending on the degree of mechanization of hazelnut harvest will increase our competitive power in international markets. Given the agricultural conditions in Türkiye, a hazelnut harvester suitable for flat and nearly flat terrain should be designed in accordance with ergonomic principles, user comfort, and workplace safety. Such a machine must offer high operational efficiency, featuring an effective mechanical sweeping mechanism to collect fallen nuts and husks, a separation unit that cleans the mixture sufficiently to preserve the performance of the husking machine, and an on-board storage system. When such a hazelnut harvester is manufactured, the harvesting cost and demand for workers for hazelnut producers will decrease, and positive results will be obtained economically. In addition, it will provide agro-technical benefits such as not damaging the branches as a result of collecting hazelnuts from the ground. Therefore, producing a machine suitable for regional orchard characteristics and hazelnut varieties represents a major step forward in advancing hazelnut mechanization, which remains a critical challenge. In Türkiye, in places where the land topography is suitable, the development of mechanical harvesting methods suitable for the planting technique and hazelnut variety will be important in terms of reducing costs.

Acknowledgements

We are very grateful to Prof. Dr. Nuh OCAK and Prof. Dr. Vedat CEYHAN, who are Member of the Agricultural Faculty of Ondokuz Mayıs University for the generous supports related to statistically and DEA analyses of this research.

Funding

The authors declare that the study received no funding.

Author contributions

A.T. conceptualization, writing – review and editing. TY. investigation, methodology and writing–original draft. All authors have read and agreed to the published version of the manuscript.

Declarations

Competing interests

The authors declare no competing interests.

References

Ayık M (1985). Mechanization in livestock. Ankara University Faculty of Agriculture Publications No: 948, Textbook No: 273, Ankara (in Turkish).

Beyhan M A (1992). Design and Manufacturing of a Hazelnut Harvesting Machine with Aspirator Suitable for Türkiye Conditions. PhD Thesis (Unpublished), Ankara University, Institute of Science, Department of Agricultural Machinery, Ankara (in Turkish).

Beyhan M A, Pınar Y (1996). A Study on the Possibility of Using a Motorized Brush Cutter in Hazelnut Root Shoot Removal. OMÜ Faculty of Agriculture, Hazelnut and Other Hard-Shelled Fruits Symposium, Proceedings Book, 119–133, 10–11 January, Samsun (in Turkish).

Beyhan M A (1996). The determination of the possibility of using an eccentric type limb shaker in the mechanical harvesting of hazelnut. Congress on hazelnut and other fruits, Agricultural Faculty, Ondokuz Mayıs University, 212-225, Samsun, Türkiye (in Turkish).

Biondi P, Monarca D, Zoppello G (1992). La Meccanizzaione Della Coltura del Nocciolo. Estratto da Macchine and Motori Agricoli-il Trattorista, n.4, s.29-48.

Bolli P, Scotton M (1987). Lineamenti di tecnica della meccanizzazione agricola. 1a Edizione. Edagricole, Bologna (Italia). 221 pp.

Caran D (1994). Investigation of Mechanical Harvesting Possibilities in Olives. Ege University, Institute of Science, Department of Agricultural Machinery, PhD Thesis (Unpublished), Bornova-İzmir (in Turkish).

Coelli T J, Rao D S P, O'Donnell C J, Battese G E (2005). An Introduction to Efficiency and Productivity Analysis. 2ndEdition, Springer, New York, 350 pp.

Dinçer H (1976). Machinery Usage Costs in Agricultural Enterprises. Türkiye Agricultural Equipment Corporation Professional Publications, Ankara (in Turkish).

Franco S, Monarca D (2001). Technical and economic aspects of hazelnut mechanical harvesting. Acta Horticulturae (ISHS) 556:445-452

Ghiotti G (1989). Macchina semovente per la raccattatura delle nocciole. Estratto dalla Rivisia di Ingegneria, Anno XX-n.3:174–183

Kadayıfçılar S, Erdoğan D (1988). Melioration Machines. Ankara University Faculty of Agriculture Publications No: 1046, Textbook No: 303, Ankara (in Turkish).

Kadayıfçılar S, Dinçer H (1972). Agricultural Machinery Management, Volume II. Ankara University Faculty of Agriculture Publications: 489, Textbook: 163, Ankara (in Turkish).

Keskin R, Erdoğan D (1992). Agricultural Mechanization (2nd Edition). Ankara University Faculty of Agriculture Publications No: 1254, Textbook No: 359, Ankara (in Turkish).

Monarca D (1995). Macchine per la raccolta delle nocciole, le più recenti innovazioni. Terra e Sole 49:629.

Tombesi A (2005). World Hazelnut Situation and Perspectives: Italy. Acta Hort. 686, 649-658.

Yıldız T (2000). Traktörle çalıştırılabilir-yerden toplama üniteli bir fındık hasat makinasının tasarımı. PhD, Ankara University, Ankara, Türkiye (in Turkish).

Yıldız T, Tekgüler A (2012). Determination of Work Efficiency in hazelnut harvesting with eccentric-type shaker. Proceedings of the 27th National Congress on Agricultural Mechanization, 5–7 September 2012, Samsun, Turkey, pp. 332–339 (in Turkish).

Zimbalatti G, Benalia S, Bernardi B, Proto A R, Smorto D (2012). Hazelnuts mechanical harvesting in Calabria: preliminary trials on work productivity. In: "Safety, Health and Welfare in Agriculture and in Agro-food Systems" International Conference, 3–6 September 2012, Ragusa, Italy, pp. 104–109.