Turkish Journal of Food and Agriculture Sciences

TURJFAS

6(1): 47-54 (2024)

Research Article

DOI: https://doi.org/10.53663/turjfas.1432844

Comparison of nut losses and foreign material separation efficiencies of hazelnut harvesting machines under different orchard yield conditions

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ARTICLE INFO

HISTORY

Received: 6 February 2024
Revised: 6 March 2024
Accepted: 7 March 2024
Online Published: 30 June 2024

KEYWORDS

Foreign material separation efficiency
Hazelnut harvesting machines
Nut losses

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ABSTRACT

In this study, the possibilities of using the prototype manufactured hazelnut harvesting machine with a mechanical efficient harvesting unit and hazelnut harvesting machine with a pneumatic efficient harvesting unit in the mechanical harvesting of hazelnuts grown in flat and near flat land conditions were examined and the nut losses and the efficiency values of separating foreign materials were determined to reveal how these machines affect the hazelnut harvesting system. For this purpose, the trials were carried out under five different orchard yield conditions (71.74, 143.48, 215.23, 286.97, and 358.72 kg ha^{-1}). As a result of the experiments, the nut loss and foreign material removal efficiency obtained by hazelnut harvesting with a hazelnut harvesting machine with a mechanical effective harvesting unit were determined between 34.39-37.92% and 96.91-95.62%, respectively. The nut losses and foreign material removal efficiency values obtained by hazelnut harvesting machine with a pneumatic effective harvesting unit were determined between 6.84-5.07% and 93.33-86.73%, respectively. The data to be obtained as a result of the study, in addition to examining the mechanical harvesting of hazelnuts, will enable the reasons for the changes that may occur in the performance characteristics of existing machines to be explained and suggestions can be made for improvement.

Citation: Sauk, H., & Beyhan, M.A. (2024). Comparison of nut losses and foreign material separation efficiencies of hazelnut harvesting machines under different orchard yield conditions. *Turkish Journal of Food and Agriculture Sciences*, 6(1), 47-54.

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1. Introduction

Türkiye has 74.50% of the world's hazelnut planting areas with an area of approximately 700.000 t ha. Hazelnuts in shell production are approximately 665.000 t and supply about 76% of the world's production. Hazelnut exports are approximately 500.000 t and 75% of the world's exports (TÜİK, 2023). Although Türkiye is the world's leading producer and exporter of hazelnuts and the sole source of livelihood for around 500.000 farmers, harvest mechanization has not reached the same level with competing countries. Hazelnut harvesting, which has an important place in the farm of our country, is done manually, but it is also done mechanically with the widespread use of hazelnut harvesting machines developed by local manufacturers recently (Beyhan and Sauk, 2018). The most prominent difference that distinguishes our hazelnuts from the varieties of other countries is that in Turkish varieties, the mature long, and tightly wrapped kernel. For this reason, ripe nuts do not fall as kernels. But, in almost all cultivars, mature fall to the ground spontaneously (Ayfer et al., 1986; Beyhan, 1992).

The healthiest way of harvesting hazelnuts is to shake the mature husked to the ground and harvest the hazelnuts from the ground. However, due to the prolongation of the harvest until the rainy periods and the drying problem, the harvest method applied in the Black Sea Region is the hand-harvesting of hazelnuts from the branch. When hazelnuts are collected by hand on branch, the buds and twigs that will form the next year's crop are also damaged. On the other hand, if the hazelnuts are harvested after being dropped to the ground by shaking, these damages are prevented, labor is saved and high yield and quality nuts are obtained since the hazelnuts are harvested at maturity (Beyhan, 1992; Beyhan and Yıldız, 1996; Bozoğlu, 1999).

Mechanical harvesting of seed kernels includes ground preparation, dropping the kernels, barreling the dropped kernels, harvesting, and cleaning. The purpose of ground preparation is to obtain a flat and compacted ground for sweeping the dropped kernels. To increase the work success of the harvesting machines, the dropped kernels should be swept to form a barrel between the rows before the harvesting process. Beyhan (1992), In his study in which he designed and manufactured an aspiration harvesting machine suitable for Türkiye conditions, tested the machine at 3 different orchard yields of 113.4, 226.8, and 340.2 kg ha^{-1} and determined that the nut loss of the machine was 4.27%, 4.87%, and 7.57%, respectively. It was reported that 2.67% of these nut losses were due to hazelnuts spilled into the brush ("ocak" in Turkish). According to orchard yields, the losses of 1.6%, 2.2%, and 4.9%, respectively, were caused by the hazelnuts that the machine could not harvest. Emphasized that the hazelnuts that could not be harvested were found in densely weeded areas and soil crevices, and it was observed that the majority of these were kernels. Ghiotti (1989), designed a hazelnut harvesting machine with a harvesting system based on the principle that chains mounted on a drum rotating against the direction of movement strike the kernels. Stated that the machine removes soil and plant residues from the harvested kernels with an airflow generated by a fan. During the harvesting, a total of 11-14% nut loss occurred due to hazelnuts left at the inside of the trees and in places where the machine could not reach, hazelnuts thrown from the cleaning unit, hazelnuts that the machine could not harvest and hazelnuts damaged while passing through the machine, and the rates of these losses were 6-7%, 3.7-5%, 0.9-1.1% and 0.33-0.51%, respectively. Pagano et al. (2010), in their study to determine the performance values of a hazelnut harvesting machine with a mechanical harvesting unit, found that the amount of foreign material in the sack constituted 10.25% of the total amount.

The possibilities of using the hazelnut harvesting machine with pneumatic effective harvesting unit (PHM) and the hazelnut harvesting machine with mechanical effective harvesting unit (MHM) manufactured by local manufacturers in the mechanical harvesting of hazelnuts grown in flat and near flat terrain conditions will be examined and the efficiency of hazelnut harvesting machines in separating nut losses and foreign materials will be determined to reveal how these machines affect the hazelnut harvesting system. The data to be obtained as a result of the study, besides examining the mechanical harvesting of hazelnuts, will enable us to explain the reasons for the changes that may occur in the performance characteristics of the existing machines and to make suggestions for improvement.

2. Materials and methods

2.1. Experimental design

Harvesting experiments, it was carried out in a farmer's orchard in the Kızılot neighborhood of Çarşamba town of Samsun city. The hazelnut orchard where the trials were carried out has Çakıldak hazelnut variety (*Corylus avellana*), which is widely grown in the region. In five ocak to determine the distribution of naturally fallen hazelnuts around the ocak, squares of 1x1 m were formed from the inside of the ocak to the outermost branch. The hazelnuts (kernel+husked hazelnut) were harvested. The harvested hazelnuts were weighed and the hazelnut weight (10% moisture(w.b.)) was determined. During the experiments, no intervention was made regarding the setting levels of MHM and PHM. During the trials, the PHM was operated at 2500 min^{-1} engine shaft speed, 3750 min^{-1} ventilator shaft speed, and 41.19 m s^{-1} delivery airspeed, while the MHM was operated at 1.60 m s^{-1} working velocity.

2.2. Determination of nuts losses

Nut losses were analyzed under 3 main groups: hazelnuts that remained in places that were not in the area of influence of the machine (inside the ocak, the base of the ocak, and above the row), hazelnuts that could not be harvested in the area swept by the machine, hazelnuts that were damaged while passing through the machine. Nut losses of hazelnut harvesting machines in each orchard yield are given as percentages (%).

The hazelnuts remaining inside the ocak, at the base of the ocak, above the row, and between the rows of five hazelnut ocak were harvested by hand and weighed. The weight of hazelnuts harvested in each area was proportioned to the yield of the ocak the percentage of hazelnuts remaining inside the ocak, at the base of the ocak, above the row, and between the rows was determined. The weight of hazelnuts that could not be harvested in the area swept by the machine and the weight of hazelnuts damaged while passing through the machine were proportioned to the total hazelnut weight to determine the percentage of hazelnuts remaining and the percentage of damaged hazelnuts.

Since the MHM could not reach the inside of the ocak, the ocak that barrel the hazelnuts with kernel+husked hazelnuts was operated in such a way that 25 cm was left to the inside of the ocak and the harvesting trials were carried out in this way. In addition, since the MHM could only harvest the hazelnuts between the rows, the hazelnuts on the rows could not be harvested because they could not reach the hazelnuts on the rows. When working with this machine, the nut losses occurring in this area are given in the places that are not in the affected area of the machine.

Since hazelnuts are harvested from the ground using the transmission hose manually moved with PHM hazelnuts on the inside of the ocak the rows can be harvested. The nut losses in these areas are indicated within the hazelnuts that the machine couldn't gather in the swept area.

The determination of the areas (inside the ocak, base of the ocak, and above the row) where MHM couldn't harvest in a standard plot (1 ha) utilized the following equation (Yıldız, 2000).

$$M_{KA}\,(\%) = [[(n-1).\,(OG + MYM.2).\,OAM.m]/10000]\,.100 \quad (1)$$

where;

M_{KA}: The area that MHM cannot harvest in a standard plot (%),

n : Number of ocak on rows in a standard plot (number),

m: Number of ocak between rows in a standard plot (number),

OG: The average width of ocak (m),

OAM: Distance between ocak centers (m),

MYM: Approach the distance of the machine to the inside of the ocak (m),

The following equation was used to determine the area (inside the ocak and base of the ocak) that PHM could not harvest in a standard parcel (1 ha).

$$P_{KA}\,(\%) = [[n.m.OG.OU]/10000]\,.100 \quad (2)$$

where;

P_{KA}: The area that PHM cannot harvest in a standard plot (%),

OU: The average length of ocak (m),

2.3. Determination of the efficiency of separation of foreign materials

The hazelnuts harvested with MHM and PHM were subjected to a separation process where dust, soil, dry twig pieces, husk crumbs, leaf particles, and weeds were removed and individually weighed. The weight of each component forming foreign materials was determined as a percentage (%) of the total material quantity. Additionally, a size analysis was conducted to evaluate foreign materials that came along with the hazelnuts in sacks, considering their types and diameter groups.

All the material thrown under the PHM and the outlet of the aspirator was harvested by spreading a cloth underneath. Similarly, for the MHM all the material thrown was captured by attaching a cloth under the conveyor and oscillating screens.

2.4. Damaged hazelnut rate

It was determined by proportioning the number of hazelnuts with partially broken shells or hazelnut kernels to the total number of hazelnut kernels taken per unit time from all output channels of the machine.

3. Results and discussion

3.1. Nuts losses

In the harvesting trials conducted with MHM and PHM, the harvesting efficiency values obtained after the hazelnuts remained in the areas not in the machine's area of influence (inside the ocak, base of the ocak, and above the row), the hazelnuts that could not be harvested in the area swept by the machine and the hazelnuts damaged while passing through the machine, and the nut losses in these areas are given in Table 1.

Table 1. Harvesting efficiency values and nut loss rate in machine harvesting trials (%)

Harvesting efficiency values and Nut loss, (%)		Orchard yield (kg da^{-1})				
		71.74	143.48	215.23	286.97	358.72
MHM	Harvesting efficiency	63.48	62.40	62.08	63.90	65.61
	Nut loss	36.52	37.60	37.92	36.10	34.39
PHM	Harvesting efficiency	93.16	94.26	94.87	94.87	94.83
	Nut loss	6.84	5.74	5.13	5.13	5.17

MHM can only harvest 77.54% of the standard parcel. The remaining 22.46% is composed of the areas that are not under the influence of the machine; inside the ocak, base of the ocak, and above the rows. PHM, on the other hand, can harvest 98.15% of the standard plot, and the remaining 1.85% are the areas inside the ocak that are not under the influence of the machine.

As can be seen from Table 1, in the harvesting of hazelnuts with MHM, the harvesting efficiency was at the lowest level at 62.08% when the orchard yield was 215.23 kg ha^{-1}, while the nut loss was at the highest level with 37.92% at this yield. When the orchard yield is 358.72 kg ha^{-1}, the harvesting efficiency is the highest at 65.61% and the nut loss is the lowest at 34.39% in this yield. Accordingly, when the orchard yields are 71.74, 143.48, 215.23, 286.97, and 358.72 kg ha^{-1}, the harvesting efficiency and nut loss rates of MHM are 63.48% and 36.52%; 62.40%, and 37.60%; 62.08% and 37.92%; 63.90% and 36.10%; 65.61% and 34.39%, respectively.

Again, as can be seen from Table 1, when hazelnut is harvested with PHM, an increase in the harvesting efficiency of the machine is observed with an increase in the garden yield from 71.74 kg ha^{-1} to 286.97 kg ha^{-1}, while nut loss decreases. With the increase in orchard yield from 286.97 kg ha^{-1} to 358.72 kg ha^{-1}, harvesting efficiency decreases, and nut loss increases.

When the orchard yield was 71.74 kg ha^{-1}, the harvesting efficiency was at the lowest level at 93.16%, while the nut loss was at the highest level at 6.84% at this orchard yield. At 215.23 kg ha^{-1} and 286.97 kg ha^{-1} orchard yields, harvesting efficiency was at the highest level at 94.87%, while nut loss was at the lowest level at 5.13% at these orchard yields. Accordingly, when the orchard yields are 71.74, 143.48, 215.23, 286.97, and 358.72 kg ha^{-1}, the change in harvesting efficiency and nut loss values of PHM are 93.16% and 6.84%; 94.26% and 5.74%; 94.87% and 5.13%; 94.87% and 5.13%; 94.83% and 5.17%, respectively.

The changes in the nut loss during the harvesting trials with MHM and PHM depended on the orchard yield of the hazelnuts that were left in the places that were not in the area of influence of the machine (inside

Table 2. Distribution of nut losses during the harvesting trials with machines (%)

	Distribution of nut losses, (%)	Orchard yield (kg da^{-1})				
		71.74	143.48	215.23	286.97	358.72
MHM	Remaining hazelnuts in areas not affected by the machine	24.78	24.78	24.78	24.78	24.78
	The machine could not be harvested in the swept area	6.90	5.57	3.89	3.76	3.76
	Hazelnuts are damaged as they pass through the machine	4.84	7.25	9.25	7.56	5.85
	Total nut loss	36.52	37.60	37.92	36.10	34.39
PHM	Remaining hazelnuts in areas not affected by the machine	3,68	3,68	3,68	3,68	3,68
	The machine could not be harvested in the swept area	2.21	1.12	0.99	0.59	0.61
	Hazelnuts are damaged as they pass through the machine	0.95	0.94	0.46	0.86	0.88
	Total nut loss	6.84	5.74	5.13	5.13	5.17

the ocak, base of the ocak, and above the row), the hazelnuts that could not be harvested in the area swept by the machine and the hazelnuts that were damaged while passing through the machine are given in Table 2.

As can be seen from Table 2, in the harvesting of hazelnuts with MHM under all orchard yield conditions, the nut loss caused by the hazelnuts remaining in the ocak, inside of the ocak above the row, which were not under the influence of the machine, was 3.68%, 4.75%, and 16.35%, respectively. Again, as seen in Table 2, the proportion of hazelnuts that could not be harvested in the area swept by the machine decreases with the increase in orchard yield. However, the hazelnuts that the machine could not harvest include hazelnut kernels and hazelnuts with partially broken shells. These are the hazelnuts that fall from the lower auger to the floor after being damaged while passing through the machine. At 71.74 kg da^{-1} orchard yield, the nut loss caused by the hazelnuts that the machine could not harvest in the area swept by the machine is 6.90% (hazelnuts with kernel+shelled hazelnuts 4.74%; hazelnuts with kernel and damaged hazelnuts 1.96%). Depending on the orchard yield (143.48, 215.23, 286.97, and 358.72 kg h^{-1}), the ratios of hazelnut kernel+husked hazelnut and hazelnut kernel+damaged hazelnut in the nut losses caused by the hazelnuts that the machine could not harvest in the swept area were 3.23% and 2.34%; 1.92% and 1.97%; 1.62% and 2.14%; 2.29% and 1.47%, respectively.

Again, as can be seen from Table 2, the ratio of hazelnuts damaged while passing through the machine increases up to 215.23 kg ha^{-1} orchard yield depending on the increase in orchard yield, while the ratio of hazelnuts damaged decreases after this orchard yield. When the orchard yield was 215.23 kg ha^{-1}, the rate of hazelnuts damaged while passing through the machine was at the highest level at 9.25%, while when the orchard yield was 71.74 kg ha^{-1}, it was at the lowest level with 4.84%.

Again, as can be seen from Table 2, when hazelnuts were harvested with PHM under all orchard yield conditions, all of the nut loss (3.68%) caused by the hazelnuts remaining in the places not under the influence of the machine consisted of the hazelnuts remaining in the ocak. The proportion of hazelnuts that could not be harvested in the area swept by the machine decreased with the increase in orchard yield from 71.74 kg ha^{-1} to 286.97 kg ha^{-1}, while it increased with the increase in orchard yield from 286.97 kg ha^{-1} to 358.72 kg ha^{-1}.

In the case of 286.97 kg ha^{-1} yield, the ratio of hazelnuts that could not be harvested in the area swept by the machine was at the lowest level with 0.59%, while it was at the highest level at 2.21% in 71.74 kg ha^{-1} orchard yield. Accordingly, depending on the orchard yield, the change in the proportion of hazelnuts that could not be harvested in the area swept by the machine is 2.12%, 1.12%, 0.99%, 0.59%, and 0.61%, respectively.

Again, as seen in Table 2, the proportion of hazelnuts damaged while passing through the machine decreased with the increase in orchard yield from 71.74 kg ha^{-1} to 215.23 kg ha^{-1}, while it increased with the increase in orchard yield from 215.23 kg ha^{-1} to 358.72 kg ha^{-1}. Accordingly, depending on the orchard yield, the change in the proportion of hazelnuts damaged while passing through the machine is 0.95%, 0.94%, 0.46%, 0.86%, and 0.88%, respectively.

3.2. Foreign material separation efficiencies

The average percentage of the foreign materials separated from the separator units of the machine and the average percentage of the foreign materials separated from the separator units of the machine and the average percentage of the foreign materials in the sack during the harvesting of the hazelnuts from the orchard ground by MHM and PHM depending on the yield of the orchard is given in Table 3.

Table 3. In harvesting trials with machines, the distribution of average foreign material in the sack (%)

Distribution of the foreign material (%)		Orchard yield (kg da^{-1})				
		71.74	143.48	215.23	286.97	358.72
MHM	in the sacks	3.09	2.38	4.79	3.22	4.38
	Separated from the separator	96.91	97.62	95.21	96.78	95.62
PHM	in the sacks	6.67	9.22	8.19	8.65	13.27
	Separated from the separator	93.33	90.78	91.81	91.35	86.73

As can be seen in Table 3, the rate of material separated from the separator units of MHM was the highest with 97.62% at 143.48 kg ha^{-1} orchard yield, while the amount of foreign material in the sack was the lowest with 2.38%. With an orchard yield of 215.23 kg ha^{-1}, the amount of foreign material separated from the separator was the lowest at 95.21%, while the amount of foreign material in the sack was the highest at 4.79%. Again, as seen in Table 3, the amount of foreign material separated from the separator units of PHM was the highest at 93.33% with an orchard yield of 71.74 kg ha^{-1}, while the amount of foreign material in the sack was the lowest at 6.67%. With an orchard yield of 358.72 kg ha^{-1}, the amount of material separated from the separator was the lowest at 86.73%, while the amount of foreign material in the sack was the highest at 13.27%.

The foreign materials separated and placed in the sack consist of soil, branch parts, dry grass, dry leaves, coarse dust, and mature parts. The distribution of the soil particles harvested by the machines under the same conditions and placed in the sacks together with the hazelnuts with kernel+shelled nuts according to their sizes is given in Table 4, and the distribution of the branch parts according to their sizes is given in Table 5 and the distribution ratios of the foreign materials harvested from the orchard ground are given in Table 6.

Table 4. Harvested by machines, kernel+husked in a sack together with the hazelnuts in the sack, distribution of soil particles according to their size (%)

Sieves Diameter (mm)	Soil Rate (%)	
	MHM	PHM
2	3.67	8.91
4	6.38	16.84
8	8.87	35.09
20	25.78	17.73
40	40.96	11.40
>40	14.34	10.03

As can be seen from Table 4, the proportions of soil classified in sieves with a diameter of 2-20 mm (as a percentage of total weight) were 44.70% for MHM and 78.57% for PHM. The proportion of soil with 40 mm and larger values is 55.30 % for MHM and 21.43 % for PHM. Soil parts with a diameter of 8-20 mm are hazelnut-sized lumps and approximately spherical soils. In the diameter group of 20 mm and above, it consists of walnut-sized lumps of soil that are approximately spherical.

Table 5. Harvested by the machines, kernel+husked in a sack together with the hazelnuts in the sack, distribution of branch particles according to their size (%)

Branch length (mm)	Rate (%)	
	MHM	PHM
20	14.99	13.48
40	46.98	32.57
60	17.82	35.12
80	12.89	14.91
>80	7.32	3.92

Table 6. Harvested by the machines, kernel+husked in a sack together with the hazelnuts in the sack, distribution of foreign materials (%)

Materials	Foreign materials rate (%)	
	MHM	PHM
Dry grass	1.67	2.01
Soil	24.39	26.47
Branch part	44.21	39.81
Husk part	10.70	12.73
Dry leaf	11.40	9.41
Coarse powder	7.63	9.57

As shown in Table 5, the proportion of branches 20-40 mm in length (as a percentage of total weight) was 61.97% for MHM and 46.05% for PHM. The proportion of 60 mm and larger branches was 38.03% for MHM and 53.95% for PHM.

As seen in Table 6, the majority of the harvested foreign materials, 68.60% for MHM and 66.28% for PHM, consisted of branch parts and soil. The majority of the soil was harvested from the weedless area inside of the ocak. The majority of the grass, branch parts, leaves, and coarse dust are materials accumulated from previous years. It is clear that if the harvesting process is carried out continuously by machine, the amount of materials such as grass, branch parts, leaves, and coarse dust remaining outside the soil will decrease.

As seen in Table 6, most of the harvested foreign material, 68.60% for MHM and 66.28% for PHM, consisted of branches and soil. Most of the soil was harvested from the weedless area at the inside of the ocak. Most of the grass, branches, leaves, and coarse dust are the materials accumulated from previous years. It is clear that if the harvesting process is carried out continuously by machine, the amount of materials such as grass, branches, leaves and coarse dust other than soil will decrease.

4. Conclusion

The total nut loss obtained from the orchard trials with MHM ranged between 34.39% and 37.92%. About 24.78% of the total nut loss is attributed to the hazelnuts remaining in areas not affected by the machine (inside the ocak, the base of the ocak, and above the rows). However, it is possible to reduce nut losses significantly in these areas by using a backpack blower, rake, or broom before harvesting, or by attaching a radial ventilator to the MHM to sweep the hazelnuts remaining inside the ocak, the base of the ocak, and above the rows into the machine's effective area. This way, it can be stated that the machine's performance will increase, and significant reductions in nut losses in these areas will occur. The hazelnuts damaged when passing through the machine were observed to have internal kernel and shell cracks. Some of the damaged hazelnuts were spilled into the area swept by the machine as whole kernels, while the majority were conveyed into the sack as internal kernels and damaged hazelnuts with shell cracks. The hazelnuts that the machine couldn't pick up in the swept area consisted of hazelnuts escaping from both sides of the chain finger-picking system and hazelnuts spilled from the machine's lower auger as internal kernels and damaged hazelnuts.

The total nut loss obtained from orchard trials with PHM varies between 6.84% and 5.07%. About 3.68% of the total nut loss is attributed to hazelnuts left in areas unaffected by the machine (above the rows). It has been observed that the machine can easily harvest hazelnuts left in the row ends and between rows using the manually operated suction tube. This situation increases the harvesting efficiency of PHM and reduces nut losses. Hazelnuts in this area should also be swept into the machine's area of influence. The hazelnuts damaged in the PHM are also in the form of grains and most of them are in the form of shell cracking. The hazelnuts that the machine could not harvest were found in weedy areas and soil crevices, and most of them were in the form of hazelnuts.

The highest separation efficiency of foreign materials (twigs, stones, soil, leaves, etc.) of MHM and PHM during the harvesting of kernel+husked hazelnuts was 97.62% (143.48 kg ha^{-1} orchard yield) and 93.33% (71.74 kg ha^{-1} orchard yield), respectively. On the other hand, the amount of foreign material coming into the sack with kernel+husked hazelnuts in these orchard yield conditions of MHM and PHM is 2.38% and 6.67%, respectively. The excessive amount of foreign material in the sack will increase the sack tying-unloading time and will cause a decrease in the work success of the hazelnut harvesting machines.

Moreover, this may result in a change in the threshing time of the husker, as more material will enter the husker. As a result, when the performance characteristics of the machines are compared, the MHM developed as a prototype will be able to provide economic and agronomic benefits for hazelnut producers such as reducing the harvesting cost and the demand for labor, the other hand, preventing damage to the trees as a result of hazelnut harvesting. Thus, by manufacturing a machine suitable for our orchard structure and hazelnut varieties, an important step will be taken for the mechanization of hazelnuts, which is one of the most important problems in our country.

Compliance with Ethical Standards

Conflict of Interest

The authors declare that they have no conflict of interest.

Authors' Contributions

Hüseyin SAUK: investigation, methodology, data curation, validation, writing - original draft. **Mehmet Arif BEYHAN**; investigation, conceptualization, data curation, review, and editing.

Ethical approval

Not applicable.

Funding

This study is supported by Ondokuz Mayıs University Scientific Research Projects Coordination Unit with numbered project PYO.ZRT.1904.11.021.

Data availability

Not applicable.

Consent for publication

Not applicable.

Acknowledgment

This article is produced from Hüseyin SAUK PhD thesis. The authors thank the Scientific Research Unit of Ondokuz Mayıs University for the financial support.

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