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DESIGN, DEVELOPMENT AND PERFORMANCE EVALUATION OF A TRACTOR OPERATED OLIVE HARVESTER

Abstract. To speed up the olive harvesting process, a tractor-driven olive harvesting machine was designed and manufactured at the Institute of Agricultural Engineering (AEI), Islamabad. This newly developed equipment was tested on the Bari Zaitoon-I cultivar for its performance evaluation. This innovative technology has proven valuable in efficiently replacing expensive manual harvesting operations with timely and economic alternative. It was experimentally evaluated at different PTO speeds, stroke lengths (SL), and vertical clamp positions (CP) on the tree to find the harvested and leftover fruit (%) and field capacity (trees/h) of the machine. Data collected was statistically analyzed by using "Statistix 8.1" software at a 5 % level of probability. The best results were recorded as 92.4 % harvested fruit, 7.6 % leftover fruit and 23.6 trees/h field capacity at the PTO speed of 300 rpm along with the stroke length of 10 cm and clamp position of 1 m on the tree trunk from the ground. The use of the developed equipment will make it possible to harvest olives in a shorter time than with manual harvesting without reducing the quality and weight of the obtained products.

Keywords: economic feasibility, field capacity, innovative technology, machine efficiency, mechanical harvesting

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ПРОЕКТИРОВАНИЕ, РАЗРАБОТКА И ОЦЕНКА РАБОТЫ МАШИНЫ ДЛЯ СБОРА ОЛИВОК, УПРАВЛЯЕМОЙ ТРАКТОРОМ

Аннотация. Для ускорения процесса сбора урожая оливок в Институте сельскохозяйственной инженерии (Исламабад) была разработана и произведена машина для сбора оливок, управляемая трактором. Новое оборудование было испытано на сорте Bari Zaitoon-I для оценки работы. Инновационная технология доказала свою эффективность при замене дорогостоящих ручных систем сбора урожая на современную и экономичную. Экспериментальная оценка проводилась при различных скоростях вращения ВОМ, длине хода (SL) и вертикальном положении зажима (CP) на стволе дерева для определения количества собранных и несобранных плодов (%), а также производительности машины (деревьев в час). Собранные данные были обработаны методом статистического анализа с помощью программы «Statistix 8.1» при 5%-м уровне вероятности. Наилучшие результаты были зафиксированы на уровне 92,4 % собранных плодов, 7,6 % несобранных плодов и производительности 23,6 дерева в час при скорости вращения ВОМ 300 об/мин, длине хода 10 см и положении зажима на стволе дерева на высоте 1 м от земли. Использование разработанного оборудования позволит производить сбор оливок в более короткие сроки по сравнению с ручным сбором без снижения качества и веса полученной продукции.

Ключевые слова: экономическая обоснованность, производительность, инновационная технология, эффективность машины, механический сбор урожая

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Introduction. Olive (*Olea europaea* L.) plants can be grown to a considerable size, they are characterized by slow growth rates and remarkable longevity. The dominance of terminal growing apices tends to inhibit the development of axillary buds in a basipetal direction. However, factors such as light exposure, soil quality, and growth regulators can influence apical dominance. Adequate light penetration is crucial for the propagation of olive flowers. Its leaves are bifacial and exhibit morphological diversity [1].

Spain, Italy, Turkey, Greece, and Morocco stand out as the primary global contributors to olive production. Spain leads the world in olive cultivation, yielding an impressive 9.8 million tons each year. Italy and Morocco follow, with annual productions of 1.87 million tons and 1.56 million tons respectively. It's important that Pakistan has a substantial land area suitable for olive farming, exceeding that of Spain. Interestingly, Spain currently dominates the global olive oil market, accounting for over 75 percent of its production [2].

Sumrah et al. [3] proposed that olive cultivation and consumption are becoming increasingly significant in Pakistan over time. Varieties of olives with larger fruit sizes hold great value for both olive growers and consumers. A study was conducted to assess the performance of various table olive varieties at the Barani Agricultural Research Institute (BARI), Chakwal in the Pothwar region of Punjab, Pakistan. Eight different olive varieties were evaluated for their growth and yield. Notably, the Gemlik, Ascolana, Hamdi, and Earlik varieties exhibited exceptional performance, yielding the highest fruit weight (6.29 g), oil recovery percentage (24.66 %), and fruit yield (22.66 kg). Considering their impressive yield and growth characteristics these varieties are well-suited for large-scale cultivation in the Pothwar region of Pakistan.

The initiative "Promotion of Olive Cultivation for Economic Development and Poverty Alleviation" was granted to the Government of Pakistan under an agreement with the Italian Government, specifically a Debt Swap Agreement. This project is currently in progress and is being implemented in partnership with the National Agricultural Research Council (NARC) and its associated research facilities situated in KPK, Baluchistan, FATA, and Punjab provinces. The Government of Pakistan is actively working on expanding olive cultivation on a substantial scale through its 'Olive Promotion Project', which is administered by NARC. It is worth noting that an estimated 2.9 million olive plants have been successfully planted across approximately 25,600 acres of land throughout Pakistan as part of this endeavour [2].

In Pakistan 3.6 million tree covering 12,500 hectares were planted and there are plans to plant 10 million more trees on additional 30,400 hectares of land. Punjab has 1.74 million hectares of cultivable wasteland. In Pothwar region of Punjab, 2,000 hectares area is under olive cultivation and additional 6,000 hectares is planned to be cultivated. In Baluchistan only around 700 acres is under olive cultivation, but it has shown to be most promising province, therefore 5,665 hectares will be under olive cultivation by 2024. In KPK 2,000 hectares were allocated for olive farming [4–7].

Lack of mechanization makes the harvesting one of the most challenging tasks in olive production. Labour shortage increases the cost of manual harvesting forcing farmers to implement new mechanized technologies. It is a difficult operation, and mechanization in development has been sluggish for a lot of reasons. With increase in cost of labor and decrease in availability of workers to harvest, the focus is on mechanical technologies to harvest the crop. Mechanical harvest technologies are focusing on semi-automatic harvesters, harvest robots, and harvest-assist platforms. Semi-automatic harvesters have not been commercialized due to excessively high occurrence of fruit damage. Harvest robots are not very common due to their low efficiency and high cost [8].

Electrical shakers are hand held devices that produce vibration with an engine or an electric motor, and these devices shake the fruit and remove it from the tree. As of now, these machines on the average are able to harvest more than 80 % of total of the weight of olives yielded on each tree in between 5 to 10 min, while the performance of these machine get adversely affected by the factors related with the design of machine and variety of tree [9].

Sola-Guirado et al. [10] suggested that the olive harvesting has traditionally been carried out manually, which could pose potential risks to the overall crop yield and profitability. Therefore, two mechanical harvesting methods, the canopy shaker harvester and the tree trunk shaker, were tested. The canopy shaker harvester proven to be more effective but requires specific layout and the management of canopy hedging to achieve an acceptable harvesting efficiency of 80 % approximately. While, the tree trunk shaker has demonstrated a higher efficiency, reaching 95 % approximately, although it remains dependent on manual labor. A high field capacity was observed in both systems, averaging at about 0.15 hectares per hour. However, the trunk shaker's efficiency decreases when considering the involvement of labor, which is estimated at about 0.01 hectares per hour per person.

In Pakistan olive harvesting is carried out manually which requires additional and highly skilled labor. Also, it is laborious job that results in delayed harvesting. This method is time consuming, labor intensive and sometimes damaging of fruit causes serious quality and weight loss that ultimately decreases profit. Moreover, the extraction of extra virgin and virgin oil requires to be performed within the 24 to 48 hours after harvesting of the olive fruit to ensure the highest quality oil. An experiment was planned by keeping in mind the market/farmer demands. An olive harvesting machine was designed, fabricated and tested at different PTO speeds, vertical clamp positions (CP), and stroke lengths (SL). The aim of this experiment was to make appropriate machine, available for olive fruit harvesting at farm level. This machine proved to be an alternative choice because of its time, labor and cost saving abilities as compared to conventional manual harvesting methods.

Materials and methods. The research objectives were pursued by designing the functional parts of the olive harvesting machine, assembling these parts and subsequently testing the developed machine under normal field conditions.

Description of Study Area. The study area for this research was an olive orchard planted in 2014 by Horticultural Research Institute (HRI) at National Agricultural Research Centre (NARC), Islamabad, Pakistan. The design and development of machine was completed at the Agricultural Engineering Institute (AEI), NARC and then the preparation of planned experiment was carried out.

Design of an Olive Harvesting Machine. The design considerations of this olive harvesting machine were based on local farm requirements and field conditions. This machine was designed for harvesting olive fruit by shaking operation. The shaking mechanism is operated by PTO of tractor. The dimensions of the olive harvesting machine are 535 mm height, 475 mm width and 745 mm length. The machine is driven at the rear of tractor by PTO mechanism with the profile of 1 3/8″, 6 splines. The main frame of the machine is made up of 100 × 100 mm steel pipe with 6 mm thickness (Figure 1). The weight of the machine is approximately 35 kg and can perform the desirable function. The design of the olive harvesting machine was made by using SOLIDWORKS Software. A tractor having 50 hp is suitable to operate the manufactured olive harvesting machine.

Main frame and 3-point hitch assembly. The main frame and three-point hitch assembly was manufactured of square steel pipe of 6 mm thickness and 100 mm width as shown in Figure 2. The material used for its manufacturing was mild steel (ASTM A36). The frame parts were carefully cut and welded for maximum durability and strength.

Rope guider assembly. The rope guider assembly was also made up of mild steel (ASTM A36) plates of 6 mm thickness and 155 × 60 mm (L × W) and a rope mounting pulley of 115 mm outer diameter and 12 mm groove width was also mounted as shown in Figure 3. The guider keeps the rope in place in the bearing so that it does not slip out of it when the shaking is applied. The rope guider assembly was designed in a way that the steel rope can be taken in any direction on the tree without any problem. The rope can be guided at any place on the tree regardless of the tree shape or height.

Shaking unit. The shaking unit of the machine was also made up of mild steel (ASTM A36) plate. The thickness of the plate was 4 mm. A pulley with 50 mm outer diameter and 12 mm groove

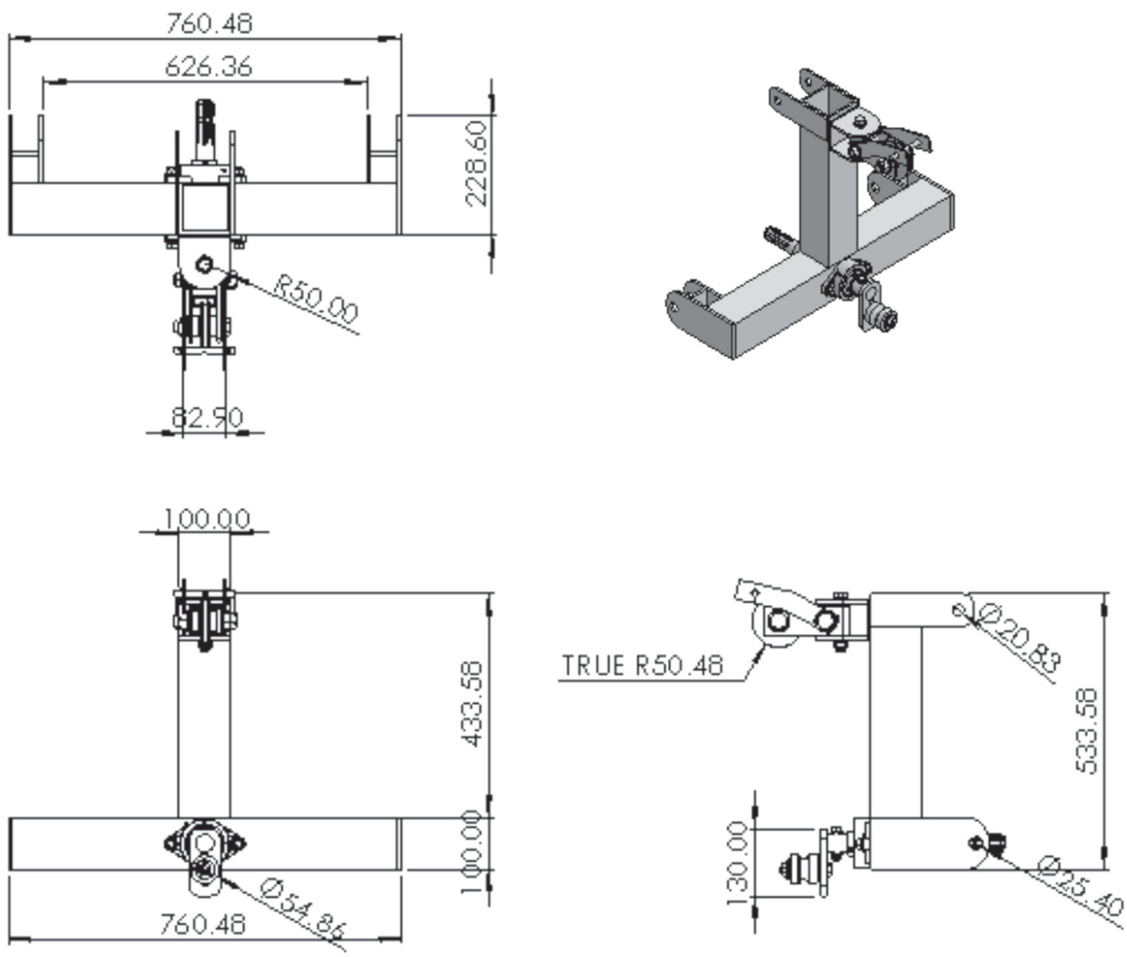

Figure 1. Blueprint and 3D drawing of the olive harvesting machine

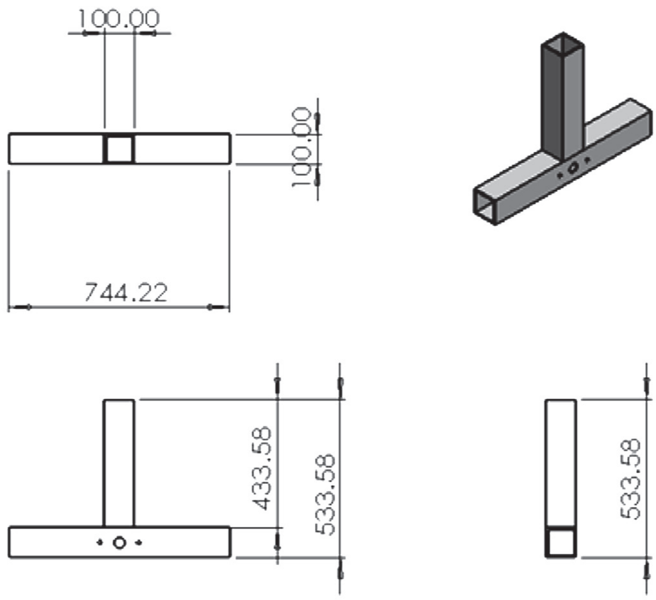

Figure 2. Blueprint and 3D design of the mainframe

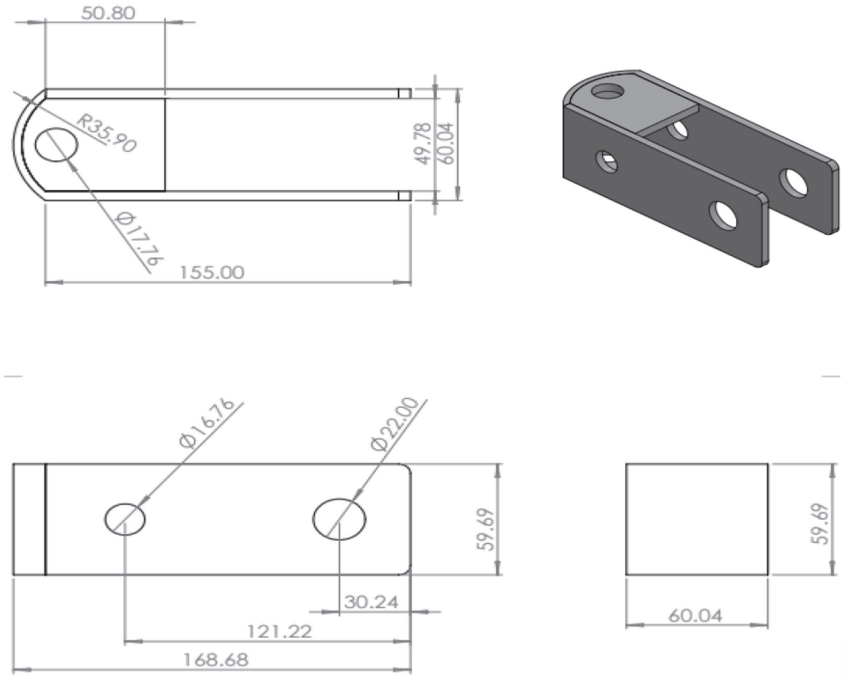

Figure 3. Blueprint and 3D design of rope guider assembly

width was also mounted on the plate for the attachment of iron rope as shown in Figure 4. The shaking unit rotated along with the rotation of the PTO shaft of tractor and the rope attached to the pulley move to and for as the shaking unit rotates. The holes drilled in the plate of the shaking unit are used to adjust the stroke lengths at 5, 10 and 15 cm.

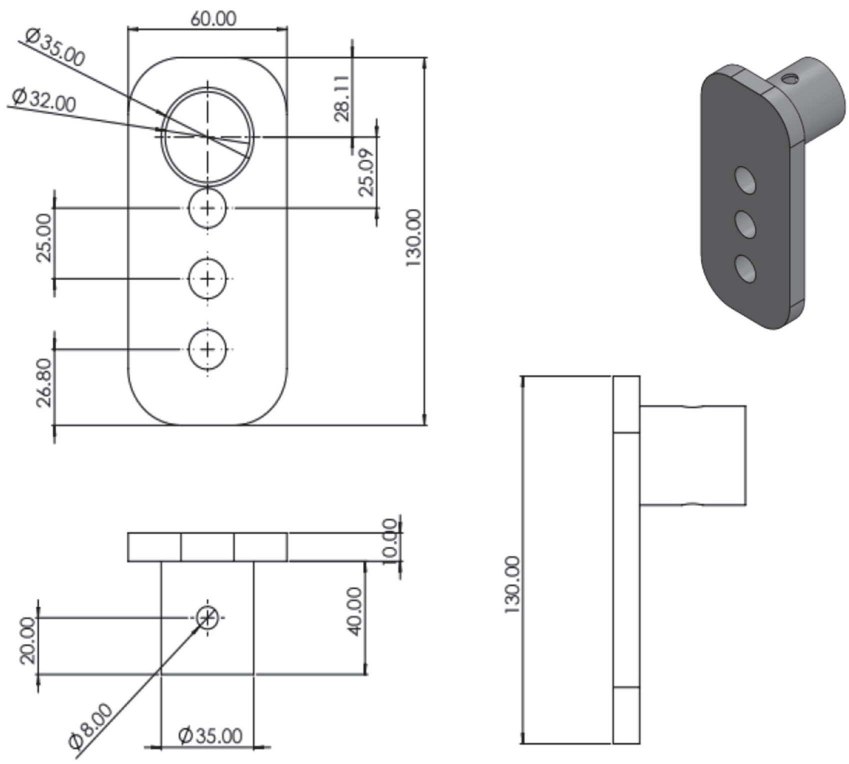

Figure 4. Blueprint and 3D design and actual picture of the shaking unit

Transmission shaft. A six-spline transmission shaft of 355 mm length and 34.8 mm diameter was used to operate the shaking mechanism of the machine as shown in Figure 5. It was attached to the PTO of the tractor by the help of a PTO shaft. The function of transmission shaft is to rotate that shaking mechanism of the machine. As the transmission shaft rotates, the shaking mechanism also rotates due to which the rope moves to and fro to provide that necessary shaking force to the tree. The material used to make the transmission shaft was high carbon steel.

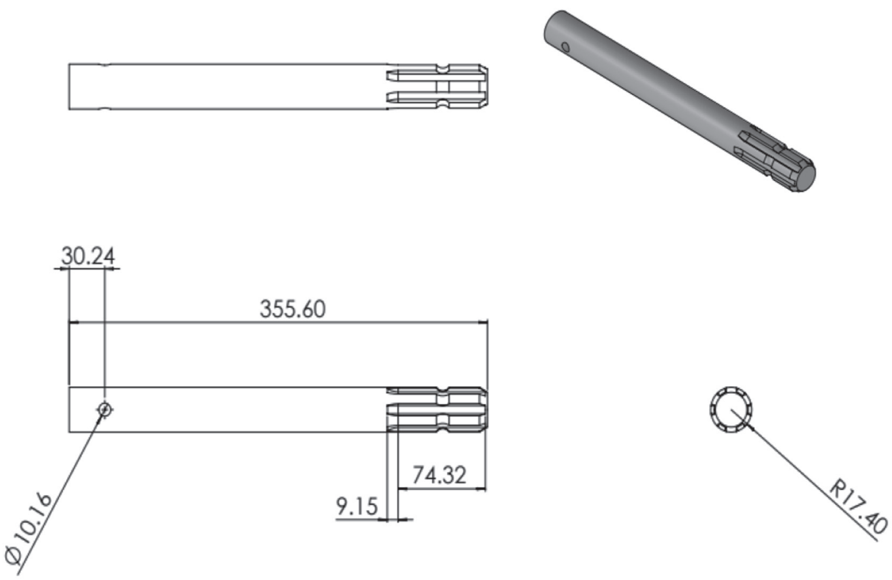

Figure 5. Blueprint and 3D design and actual picture of transmission shaft

Steel wire rope. A steel wire rope of 10 mm diameter and 10 m length. This rope was attached to shaking mechanism at one end and with tree to the other end by the help of a belt. A heavy duty nylon clamp belt was used along with rope to minimize the tree damage.

Olive Variety. The experiment was performed on the Bari Zaitoon-I cultivar of olive which are commonly cultivated in Pakistan. The most favorable period for olive harvesting is when the fruits are ripe and the oil is fully available in them.

Experimental Treatments. The performance of the olive harvesting machine was tested for harvested fruit (%), leftover fruit (%) and field capacity (trees/h), at different PTO speeds (250, 300 and 350 rpm), different levels of clamp belt from ground (0.5; 1.0; 1.5 m), and stroke lengths (10, 15, 20 cm) [11].

Lab and Experimental Measurements. *Lab measurements.* The lab measurements comprised some tree and fruit properties. The detachment force, size and mass of fruit were measured. The tree properties included stem diameter, length and bending stress.

The olive fruit is strongly attached to the limb. Therefore, the fruit removal force to weight ratio is usually high. The fruit removal force can be calculated by equation (1) [12]:

$$F = ma, \tag{1}$$

where F – fruit removal force; m – mass of fruit; a – acceleration by machine.

The fruit removal force must be greater than the fruit detachment force. Fruit removal force can be adjusted by changing the PTO speeds, clamp positions and stroke lengths.

The stress on tree trunk was measured as equation (2) [13]:

$$\sigma_b = \frac{10^{-6} \cdot F \cdot L \cdot d / 2}{\frac{\pi}{64} d^4}, \tag{2}$$

where σ_b – bending stress, MPa; F – load applied, N; L – distance between base and location of load, m; d – trunk diameter, m.

Experimental measurements. The developed machine was operated in the field at different PTO speeds (rpm), clamp heights (m) and stroke lengths (cm). A tarpaulin was placed under the tree for the collection of fruit.

The harvested fruit (HF, %) was calculated from equation (3) according to [14]:

$$\mathrm{HF} = \frac{N_1}{N_2} 100, \tag{3}$$

where N_1 – weight of fruit harvested, kg; N_2 – total weight of fruit on the tree, kg.

The leftover fruit (LF, %) was calculated by equation (4):

$$\mathrm{LF} = \mathrm{HF} - 100. \tag{4}$$

The field capacity (F_c, trees/h) was calculated by equation (5) [15], according to

$$\mathrm{F_c} = \frac{3600}{\mathrm{TV_t} + \mathrm{TDV}}, \tag{5}$$

where TV_t – shaking time per tree, s; TDV – time to move tractor/machine from one tree to another, s.

Statistical Analysis. Experimental data were statistically analysed by using Two-Way Anova (Factorial Design) in "Statistix 8.1" software at a 5 % level of probability.

Results and Discussion. The performance of the newly developed machine was evaluated in terms of harvested fruit percentage, leftover fruit percentage, and time required to harvest a tree. The machine was evaluated at three different PTO speeds (250, 300 and 350 rpm), clamp positions on the tree from the ground (0.5; 1.0; 1.5 m) and stroke lengths (5, 10 and 15 cm). Results for various parameters concerning different treatments are discussed as follows.

The harvested fruit percentage of this machine was quantified during the olive harvesting season of 2023. The machine was subjected to different PTO speeds, clamp heights and stroke lengths.

At the PTO speed of 250 rpm and the clamp positions on the tree from the ground (0.5; 1.0; 1.5 m) and stroke lengths (5, 10 and 15 cm), the maximum mean percentage of the harvested fruit (88.5 %) was observed at the clamp position of 1 m and stroke length of 10 cm, while the minimum mean percentage (71.6 %) was observed at the clamp position of 1.5 m and stroke length of 15 cm. At the PTO speed of 300 rpm and the clamp positions on the tree from the ground (0.5; 1.0; 1.5 m) and stroke lengths (5, 10 and 15 cm), the maximum mean percentage of the harvested fruit (92.4 %) was observed at the clamp position of 1 m and stroke length of 10 cm, while the minimum mean percentage (77.1 %) was observed at the clamp position of 0.5 m and stroke length of 5 cm. At the PTO speed of 350 rpm and the clamp positions on the tree from the ground (0.5; 1.0; 1.5 m) and stroke lengths (5, 10 and 15 cm), the maximum mean percentage of the harvested fruit (88.5 %) was observed at the clamp position of 1 m and stroke length of 10 cm, while the minimum mean percentage (76.1 %) was observed at the clamp position of 0.5 m and stroke length of 15 cm as shown in Figure 6.

The results of this experiment are parallel with the outcomes of [16], who showed that harvested fruit equal to or higher than 85 % are considered as the breakeven point for mechanical harvesting of olives with trunk shakers.

The machine was subjected to different PTO speeds, clamp heights and stroke lengths. The maximum mean harvested fruit percentage (92.4 %) was observed at the PTO speed of 300 rpm, stroke length of 10 cm and the clamp position of 1 m from the ground.

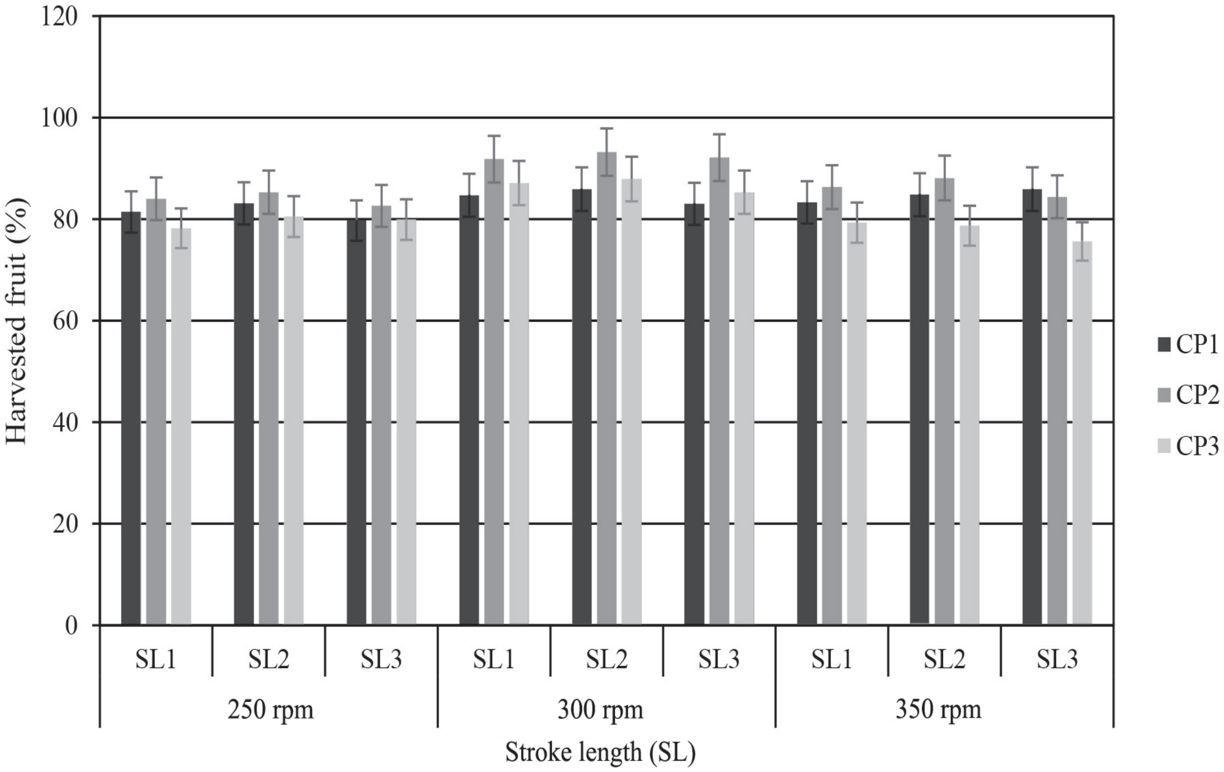

Figure 6. Harvested fruit (%) at different PTO speeds, clamp heights and stroke lengths

The leftover fruit percentage of this machine was calculated during the olive harvesting season of 2023. The machine was subjected to different PTO speeds, clamp heights and stroke lengths.

At the PTO speed of 250 rpm and the clamp positions on the tree from the ground (0.5; 1.0; 1.5 m) and stroke lengths (5, 10 and 15 cm), the maximum mean percentage of the leftover fruit (28.3 %) was observed at the clamp position of 1.5 m and stroke length of 15 cm while the minimum mean percentage (11.5 %) was observed at the clamp position of 1 m and stroke length of 10 cm. At the PTO speed of 300 rpm and the clamp positions on the tree from the ground (0.5; 1.0; 1.5 m) and stroke lengths (5, 10 and 15 cm), the maximum mean percentage of the leftover fruit (22.8 %) was observed at the clamp position of 0.5 m and stroke length of 5 cm while the minimum mean percentage (7.6 %) was observed at the clamp position of 1 m and stroke length of 10 cm. At the PTO speed of 350 rpm and the clamp positions on the tree from the ground (0.5; 1.0; 1.5 m) and stroke lengths (5, 10 and 15 cm), the maximum mean percentage of the leftover fruit (23.8 %) was observed at the clamp position of 0.5 m and stroke length of 15 cm, while the minimum mean percentage (11.5 %) was observed at the clamp position of 1 m and stroke length of 10 cm as shown in Figure 7. The outcomes are in line with the results of [17], who found that yield loss was found equal to 9.1 % for mechanical harvesting of olives with trunk shakers.

The machine was subjected to different PTO speeds, clamp heights and stroke lengths. The minimum mean leftover fruit percentage (7.6 %) was observed at the PTO speed of 300 rpm, stroke length of 10 cm and the clamp position of 1 m from the ground.

The field capacity of this machine was calculated during the olive harvesting season of 2023. The machine was subjected to different PTO speeds, clamp heights and stroke lengths.

At the PTO speed of 250 rpm and the clamp positions on the tree from the ground (0.5; 1.0; 1.5 m) and stroke lengths (5, 10 and 15 cm), the maximum mean field capacity (16.4 trees/h) was observed at the clamp position of 1 m and stroke length of 10 cm while the minimum mean field capacity (9.4 trees/h) was observed at the clamp position of 1.5 m and stroke length of 5 cm. At the

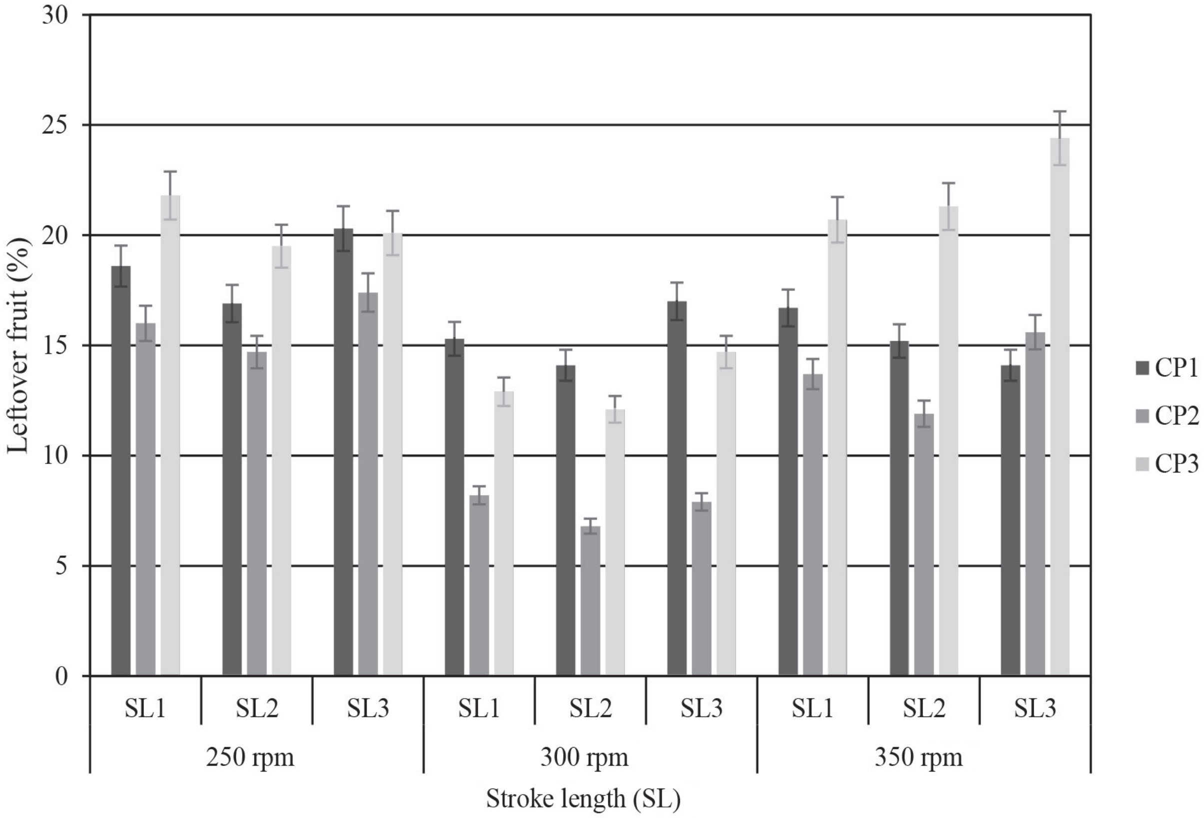

Figure 7. Leftover fruit (%) at different PTO speeds, clamp heights and stroke lengths

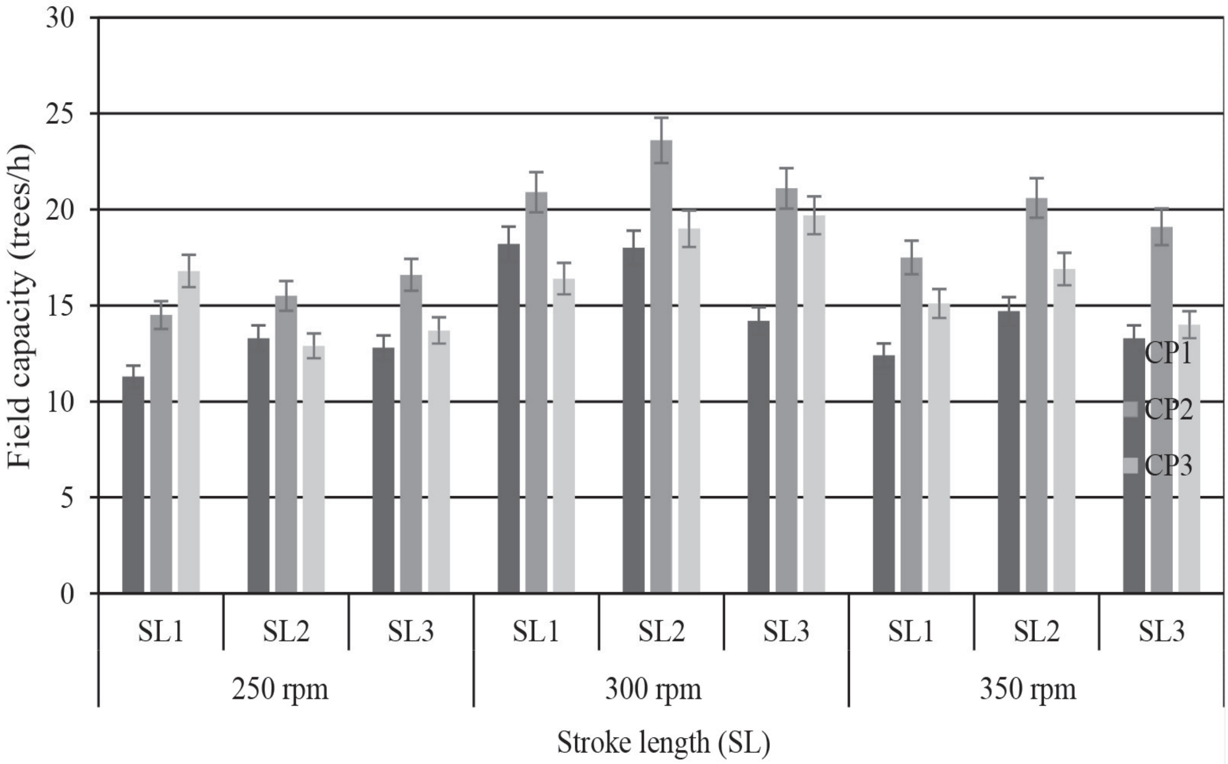

Figure 8. Leftover fruit (%) at different PTO speeds, clamp heights and stroke lengths

PTO speed of 300 rpm and the clamp positions on the tree from the ground (0.5; 1.0; 1.5 m) and stroke lengths (5, 10 and 15 cm), the maximum mean field capacity (21.8 trees/h) was observed at the clamp position of 1 m and stroke length of 10 cm while the minimum mean field capacity (11.5 trees/h) was observed at the clamp position of 1.5 m and stroke length of 10 cm. At the PTO speed of 350 rpm and the clamp positions on the tree from the ground (0.5; 1.0; 1.5 m) and stroke lengths (5, 10 and 15 cm), the maximum mean field capacity (21.1 trees/h) was observed at the clamp position of 1 m and stroke length of 10 cm while the minimum mean field capacity (11.1 trees/h) was observed at the clamp position of 0.5 m and stroke length of 5 cm as shown in Figure 8. The findings revealed that field capacity was parallel to the findings of [15], who found that field capacity/work rate were 22–26 trees/h for mechanical harvesting of olives with trunk shakers.

The machine was subjected to different PTO speeds, clamp heights and stroke lengths. The maximum mean field capacity (21.8 trees/h) was observed at the PTO speed of 300 rpm, stroke length of 10 cm and the clamp position of 1 m from the ground.

Status of Mechanically Harvested Tree. The trees harvested mechanically showed no noticeable damage. There was no instant damage or bruising evident on the branches during the shaking operation, close examination shown insignificant bruising. Interestingly, bruising and slight damage may have a good impact on ethylene levels, which can stimulate floral bud induction and improve flowering in succeeding seasons. It’s commonly observed that an increase in flower initiation occurs in the season after mechanical harvesting, likely due to potential phloem obstruction caused by the vibrating action [18].

Conclusion. Indigenously developed olive harvesting machine performed better at the PTO speed of 300 rpm, with stroke length of 10 cm and the clamp position of 1 m from the ground with the maximum mean harvested fruit percentage (92.4 %) and field capacity (21.8 trees/h) with the minimum mean leftover fruit percentage (7.6 %).

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