Zoo Botanica
ISSN: 3007-2050 (E), 3007-2042 (P)

Review Article

Prospects and Scope of Olive Mechanization: A Review

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ABSTRACT

Olive is one of the most globally recognized high-value crop mostly utilized for its oil, with 4 million hectares cultivated in the Mediterranean area. The production procedure involves many stages: nursery raising, out-planting, interculture, irrigation, plant protection, pruning, harvesting and processing. Each stage is very important and for this purpose, the entire sector is implementing strategies for mechanization of the whole production process for more economical, time-saving, and sustainable processes. This review aimed to carry out an overview of mechanization in olive production and its processing. Related literature has been thoroughly studied, highlighting the increase in the adoption of mechanical approaches in the olive production process. The results of the review reflect diversification in the field of mechanization throughout the olive production process. The use of mechanization in nursery raising, out-planting, interculture, irrigation, plant protection, pruning, harvesting, and processing has a great impact on the whole production cycle. Special focus was given to major machinery used from olive planting to processing.

Keywords: Harvesting; interculture, olive; processing; production; pruning.

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Article History
Received: November 01, 2023
Accepted: December 05, 2023
Published: December 28, 2023

INTRODUCTION

Olive trees *(Olea europaea L.)* are well-suited for sub-tropical climate and are primarily cultivated for their oval-shaped fruits. These fruits are widely used for extracting non-drying edible oil and are also consumed raw in various dishes such as soups, salads, and pickles. Olives are a rich source of polyunsaturated fatty acids (PUFA) and are entirely free from cholesterol. It provides a positive edge to olive oil over the other edible oil from the human health view point. The Mediterranean region is particularly abundant with olive trees due to their adaptability to the local climate. The global production of olive oil is approximately 460 million gallons, with Spain, Italy, Greece, Portugal, Tunisia, Turkey, and Syria being the largest producers (Verma et al., 2012). The olive tree's origins can be traced to the *Laurophyllus* forest around the Thetys. Olive 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 flowering. Its leaves are bifacial and exhibit morphological diversity. Its trees have evolved to cope with environmental stress, reflecting their evolution in a Mediterranean climate (Mukrimaa et al., 2016).

Olive Nursery Raising

Olive seedlings and root cuttings are often planted in containers like clay pots, plastic tubes, or metal cans, using a potting mixture that typically consists of one part loam soil, one part sand, and one part organic matter like leaf mold or peat moss. Numerous propagation media are utilized, including soil, sand, peat, sphagnum moss, vermiculite, perlite, leaf mold, sawdust, and grain husks. Establishing an olive nursery typically involves several steps i.e. site selection, wherein a careful consideration is given to choose an appropriate nursery location which meets the required environmental conditions, soil preparation which is that soil is prepared to create an optimal environment for nurturing olive seedlings. The selection of healthy scion wood that is free from diseases or insects for grafting or budding onto the rootstock. Effectively managing an olive nursery is paramount to producing robust and healthy olive seedlings, a critical factor in the successful establishment of an olive orchard. Proper attention should be given to these physical resources is essential for the nursery's upraising (Olive Nursery Raising Manual, 2016).

Figure 1. Olive nursery raising.

Olive Plantation

A post-hole digger is a device that attaches to a tractor's power take-off (PTO) shaft. It harnesses the rotational power from the tractor's PTO shaft to drive an auger. A top support arm, which is linked to the top pin of the tractor's three-point hitch, provides stability for the gearbox responsible for transferring rotational energy to the auger. The primary function of the auger is to excavate holes in the soil, commonly used for planting trees or plants. Remarkably, this machinery is also well-suited for the excavation required in olive plantation (Li et al., 2018). Globally, olive cultivation systems are implemented in various regions, catering to diverse terrains such as sloping landscapes, mountainous regions, and flat areas. Recent transformations within these systems have primarily been driven by the necessity for mechanized harvesting, increased input utilization (especially chemicals), and the adoption of drip irrigation. These changes have resulted in a wide spectrum of olive cultivation practices, impacting both the quantity and quality of olive oil produced. Three primary production systems have been examined. Intensive Orchards (IS) feature tree densities ranging from 200 to 400 trees per hectare. High-density orchards (HD) encompass tree densities ranging from 400 to 700 trees per hectare. Super-high-density orchards (SHD) boast tree densities exceeding 1,500 trees per hectare. An analysis of these three modern orchard designs (IS, HD, and SHD) conducted across both the Northern and Southern Hemispheres tells us about the variations between countries concerning several key variables (Tous et al., 2014).

The expansion of super-intensive olive plantings has raised significant concerns, both from environmental and social perspectives. A key issue is the limited number of cultivars currently in use, typically only two, in contrast to the more than 100 olive cultivars grown extensively worldwide. Olive cultivation encompasses over 11 million hectares globally, with diverse regions in terms of climate, soil, and environmental stress factors. Traditionally, olive trees have coped with various biotic and abiotic stressors. However, due to the current shortage of cultivars suitable for super-intensive systems, there is a pressing need for new cultivation models in the short term. This approach aims to address the challenges posed by super-intensive plantings while promoting sustainable and efficient olive cultivation practices (Lo-Bianco et al., 2021).


Figure 2. Post hole digger.

Traditional olive orchards, typically consisting of 80 to 100 trees per hectare, often exhibit relatively low productivity and higher operating costs, particularly for activities like harvesting and pruning. Since the 1970s, there has been a notable shift towards expanding olive cultivation through the intensification of orchards. Numerous experts have recommended adopting higher planting densities, ranging from 200 to 500 trees per hectare. These orchards are usually designed for drip irrigation and are well-suited for mechanical harvesting using trunk shakers. They offer the advantage of higher yields and relatively lower to medium production costs compared to traditional orchards. This system is particularly conducive to continuous mechanical straddle harvesting and can achieve higher produce within a few years after planting. To optimize the efficiency of mechanical harvesters, it is essential to manage tree vigor, controlling tree size while maintaining high productivity. However, one challenge with SHD orchards is the limited availability of olive cultivars adapted to this system (Tous, 2011).

The anticipated increase in demand for mechanized tree planting is a subject addressed in this dissertation, which focuses on the evaluation of mechanized tree planting practices and presents recommendations for enhancing its current productivity. While mechanized planting demonstrates superior productivity compared to manual methods, it has yet to achieve cost competitiveness. However, there is potential to reduce mechanized planting costs through enhanced efficiency, primarily through skilled operators and strategic worksite selection, thus making it a more economically viable option than excavator spot mounding followed by manual planting. The effectiveness of mechanized tree planting depends on fulfilling several criteria, including machine reliability, skilled machine operators, appropriate worksite selection, access to high-quality seedlings, and a consistent supply of seedlings to the worksite (Laine, 2017).

Olive Plant Protection

Pesticide applications are a necessary component of ensuring the proper growth of crops and, consequently, the economic viability of farmers. However, the mismanagement of pesticides has given rise to significant environmental concerns. In the context of olive cultivation, which is a crucial crop in Spain, this issue is particularly pressing for several reasons. Firstly, the deficiency of awareness and training often results in farmers and technicians struggling to plan treatments effectively, leading to the overuse of pesticides to ensure their biological efficacy. Additionally, the traditional nature of olive farming and the unique structural characteristics of olive trees, such as their large size, irregular crown shapes, wide spacing between trees and rows, and the presence of steep terrain, present distinct challenges in conducting pesticide spray applications effectively to reach the tree canopy (Miranda Fuentes and Juan Agüera, 2017).

https://doi.org/10.55627/zoobotanica.001.02.0613

Figure 2. Super high density olive orchard.

In Mediterranean olive cultivation, effective management of significant pests such as the olive fly, olive moth, and black scale is vital. Typically, a combination of six insecticides (Malathion, Quik, Cidial, Dimethoate, Actellic, and and two mineral oils (Super misrona and Kemesol) is employed for this purpose. An evaluation of these six insecticides revealed their efficacy in reducing parasitism by approximately 80–95%. These insecticides were classified as having a moderate impact when applied at the recommended field doses. In contrast, the two mineral oils demonstrated a lower reduction in parasitism, around 25%, resulting in their categorization as non-harmful to the adult stage of the parasite. Additionally, a persistence test conducted on olive foliage indicated that Malathion, Quik, and Actellic showed slight persistence, while Cidial, Dimethoate, and Deltamethrin displayed moderate persistence (Youssef et al., 2004).

A new generation of air blast sprayers has been created in response to mounting concerns about the possible harm to the environment that inappropriate pesticide applications in olive groves may cause. These innovative sprayers were precisely engineered to enhance application efficiency and address the restrictions commonly associated with traditional sprayers practiced in both conventional and intensive orchards. The development process involved the creation of three distinct prototype sprayers. The outcomes of the field tests indicated that these prototype sprayers held significant potential in terms of expressively improving efficiency when compared to conventional equipment. Notably, when applying an equivalent volume of liquid, the second and third prototypes exhibited an impressive increase in coverage by an average of 61% and 46%, respectively, in both intensive and conventional cultivation systems, surpassing the performance of a commercial air blast sprayer (Miranda-Fuentes et al., 2017). In the context of applying plant protection products (PPPs) to isolated olive trees, it is common practice to utilize traditional air-assisted sprayers, although they may not be ideally suited to the unique characteristics of olive trees. In recent years, efforts have been made to enhance technical aspects such as canopy detection and automated proportional dosing, there has been a notable lack of attention given to adapting sprayers to the specific demands of olive cultivation. To address this gap, three prototype sprayers were developed for use in both traditional and intensive olive cultivation systems. The primary goal of these prototypes was to enhance the efficiency of PPP applications. Field trials of these sprayers were conducted in two different olive groves, with adjustments made based on the dimensions of the olive trees. The evaluation included the measurement of various parameters, including spray deposition, coverage, drift, and ground losses.

These parameters were assessed by placing appropriate collectors in five trees per cultivation system. The performance of the sprayers exhibited significant variations between the two cultivation systems. This underscores the vital importance of tailoring spraying techniques to the specific requirements of crops such as olives. Such customization can lead to substantial improvements in spray quality and overall efficiency, especially in challenging agricultural settings (Godoy-Nieto et al., 2022).

Figure 3. Ballast sprayer.

It is common practice to place plastic sheeting, typically about 1-meter-wide, around the base of the trees for effective weed control and to preserve moisture and maintain temperature conditions near the root system of olive trees. This mulching offers several advantages, including facilitating better tree growth and simplifying orchard management. It is crucial to maintain a consistent water supply immediately after planting to prevent stress on the newly established olive trees. This involves irrigating when natural water resources are insufficient. This practice holds particular significance during the initial two years following planting, as it allows the olive trees to establish roots that can reach into the deeper layers of soil with higher moisture levels. During this early growth phase, each plant generally requires a daily water supply of 2-3 liters to support proper growth. In cases where rainfall is inadequate, it is advisable to plan for supplemental irrigation every week, especially during dry months. This irrigation regimen helps promote robust growth and overall health for young olive trees (International Olive Council., 2007).

Olive Pruning

Pruning is an essential practice in olive cultivation as it serves to control tree size, facilitate harvesting, and maintain a harmonious balance between reproductive and vegetative growth. Post-harvest pruning demands the most significant allocation of labor resources throughout the entire crop cycle. However, the increasing scarcity of skilled labor and the rising cost associated with it have compelled farmers to prune less frequently than ideal. The invention of a pruning machine equipped with rotating saws has proven beneficial in addressing the labor shortage issue and improving overall efficiency. These rotating saws are employed to trim the extra branches of olive trees. Mechanical pruning has significantly reduced the labor requirement to only 4 hours of work per 100 trees, as compared to the laborious 128 hours needed for hand pruning for the same job. Furthermore, a more efficient approach is practiced when mechanical pruning is followed by selective manual pruning, reducing the labor requirement to 21 hours per 100 trees. Typically, the pruning machines used are equipped with five circular saws, each boasting a diameter of 55 cm and rotating at a speed ranging from 2200 to 2300 revolutions per minute. These saws collectively provide a cutting edge that spans 2-5 meters. The machine is mounted at the front of a self-propelled lifting truck powered by a 30 kW engine, which drives both the machine's movement and the hydraulic system (Giametta and Zimbalatti, 1997).

Mechanical pruning techniques in the olive industry are rapidly embracing, which encompass practices such as topping and lateral hedging using rotating disks, elevating the lower portion of the tree canopy through mechanized trimmers, and the removal of individual branches with pneumatic cutters. In super-high-density (SHD) orchards, it is essential to renovate branches to ensure the fruit is consistently located near the trunk for continual production. Mechanical pruning is most useful in large SHD orchards due to the high number of trees and in high-density (HD) orchards owing to the tree size. However, some manual pruning, particularly the removal of internal and dead branches, may still be required in most orchards that undergo mechanical pruning (Connor et al., 2014).

Figure 4. Mechanical olive pruning.

Dias et al. (2012) found that in Portugal, traditional olive groves, typically containing around 100 olive trees per hectare, face the challenge of increasing pruning costs over time. Consequently, farmers often opt to extend the intervals between pruning sessions. To address the need for a cost-effective and less labor-intensive alternative to manual pruning, field trials were initiated. These trials included three distinct approaches: manual pruning with a Chain Saw, mechanical pruning which is carried out using a tractor-mounted circular disc-saws cutting bar, and mechanical pruning followed by manual pruning: This involves initial mechanical pruning, followed by supplementary manual pruning. Over 8 years, comprehensive evaluations were conducted annually to assess olive production and harvesting efficiency. Olives were harvested using a trunk shaker, with any residual un-harvested fruits being collected manually. The degree of pruning for mechanical pruning was notably higher at 487 trees per hour per worker (trees h–1man–1) compared to the consistent rate of 20 trees h–1man–1 for both manual pruning and mechanical cum manual pruning. Throughout the 8 years, mechanical pruning consistently demonstrated a higher average yield of 36.4 kg per tree per year, significantly surpassing the 30.1 kg per tree per year achieved through manual pruning. Moreover, this yield was statistically similar to the 34.1 kg per tree per year produced by the mechanical cum manual pruning method. The efficiency of the shaker was expressively influenced by the year, with rates varying between 72% and 96%. Nonetheless, there were no significant differences in harvesting efficiency observed between the various pruning treatments.

Intercultural Practices in Olive Orchards

Manual weeding requires more man hours while the labour shortage is a major challenge for this operation. To combat this issue, weeder machines have been developed to mitigate time, labor, and wedding expenses, with mechanical weeding costing only a fraction of manual weeding. In the context of wide-row crops, a technology involving the adaptation of tractors with narrow iron wheels (150 mm) has emerged as an efficient solution for weed management. This customized machinery boasts impressive weeding efficiency, achieving a rate of 97%, and field efficiency at 81%, all while maintaining a reasonable cost. Its versatility allows for application in check row planting methods across a range of crops, including eucalyptus, casuarina, guava, olive, and more. In contrast to tractor-drawn cultivators, which are susceptible to interruptions due to weed accumulation, rotavators are employed for weeding. This technology finds its utility in various domains, including biodiesel plantations, farm forestry, and plantation schemes within the pulp and paper industry. Beyond providing labor-saving solutions, it also promotes sustainable agricultural practices that align with the evolving needs of modern agriculture (Tajjudin, 2017).

Figure 5. Weeding in an olive orchard.

A novel concept has been introduced involving the use of a rotary offset tiller, often referred to as an orchard tiller, to perform more precise intercultural operations among plants. With several models of rotary offset tillers available, the quality of their work performance becomes a pivotal factor when selecting an efficient, effective, and suitable machine for orchard applications. Consequently, the selection of appropriate and efficient orchard tillers based on intercultural work quality parameters holds significant importance. Several intercultural machines, including the Rineri, offset tiller, Saktiman offset tiller, and Side shift tiller for orchards, underwent an analysis of their intercultural work quality to assess their suitability. The work quality achieved with the side shift tiller was considered superior compared to other orchard tillers, and it efficiently incorporated all stubble and residues into the soil. Consequently, the side shift tiller is recommended for farmers for intercultural operations in orchards (Kumar et al., 2021).

Intercultural operations in agriculture encompass essential activities conducted between sowing and harvesting to promote crop growth. These tasks involve soil preparation, weed control, aeration, and moisture retention, and they make use of various tools such as hoes, rotary offset tillers, and cultivators. Evaluating intercultural implements plays a critical role in optimizing farming practices. In a recent study, the rotary offset tiller was identified as the most suitable implement based on several criteria. It demonstrated efficiency with lower draft requirements and reduced fuel consumption, ensuring cost-effectiveness in agricultural operations. Furthermore, the implement effectively pulverized the soil, incorporated crop residues, and achieved a high field performance index, indicating its overall effectiveness. Although the rotary offset tiller had a lower field capacity, its performance metrics make it a promising choice for farmers. This ultimately leads to enhanced production and profitability. Further research may be required to assess the suitability of the rotary offset tiller in diverse agricultural contexts (Namdev et al., 2019).

Irrigation in Olive Orchards

A highly efficient standalone direct pumping photovoltaic irrigation system has been proposed to address deficit irrigation needs in olive orchards. To determine the economically optimal system design, a simulation model has been developed. This model comprises various sub-models, including the photovoltaic power generation capacity sub-model, the direct pumping management sub-model, and the sub-model responsible for assessing the economic and productive response of the crop to water application. The simulation model operates by varying the peak power values of the photovoltaic system. It calculates the water and energy balance within the photovoltaic irrigation system and predicts crop yields for different scenarios. Additionally, the model evaluates the investments and operational costs associated with the system and computes the net economic returns for the farmer. The primary objective of the model is to identify the optimal system design that maximizes economic profitability. It is important to note that the economically optimal designs recommended by the model do not necessarily involve fully irrigating the crop; instead, they often entail implementing deficit irrigation practices. This approach ensures efficient utilization of water resources while still maintaining economic viability in olive orchards (López-Luque et al., 2015).

Olive trees are traditionally grown without irrigation, relying on rain-fed conditions. However, the substantial increase in yield with even limited irrigation has sparked interest in irrigated agriculture for olives. The primary objective is to optimize sustainable irrigation practices in regions with over-exploited aquifers while studying the impact of different irrigation approaches on the composition and quality of virgin olive oil. Additionally, the total phenol content in the olives, which contributes to the bitterness of the resulting oils, reduced notably as the amount of applied water increased. This finding is noteworthy as high phenol levels, characteristic of virgin olive oils, can influence consumer preference. Interestingly, one of the RDI (Responsive Drip Irrigation) strategies yielded olive oil with composition and quality similar to that obtained with 100% ETc while using less water. This highlights the potential for efficient water management in olive cultivation (Gómez-Rico et al., 2007).

In numerous olive-growing regions, the available water resources for irrigation are often insufficient to meet the water requirement for full irrigation (FI). As a result, the practical application of FI in olive orchards becomes challenging. Moreover, it's important to recognize that relying solely on FI may not necessarily yield the highest net incomes from orchard operations. Typically, for most fruit tree species, FI is recommended primarily during the initial years after planting to expedite orchard establishment. Subsequently, irrigation management should be tailored based on the species' response to deficit irrigation (DI). In the context of olive cultivation, once the orchard has successfully established itself, irrigation can be significantly reduced without causing a substantial negative impact on production. This suggests that olive orchards can thrive with more conservative water management practices once they have reached maturity (Fernández et al., 2018).

Figure 6. Irrigation in olive orchard.

There is currently no consensus regarding the optimal irrigation method for super-high density (SHD) olive orchards. The goal of this study was to create and assess a regulated deficit irrigation (RDI) strategy aimed at achieving a sustainable balance between water conservation, tree vigor, and oil production. This RDI strategy was implemented and evaluated over three years in an olive orchard with a planting density of 1,667 trees per hectare. Two levels of irrigation reduction were implemented: 60RDI, designed to replace 60% of the irrigation needs (IN), and 30RDI, aimed at replacing 30% of IN. A control group received full irrigation (FI), with IN totalling 4,701 cubic meters per hectare. Among the different treatments, the 30RDI approach demonstrated the most favourable balance between water conservation, tree vigor, and oil production. With an annual irrigation amount (IA) of 1,366 cubic meters per hectare, representing a 72% reduction in water usage compared to FI, the decrease in oil yield was only 26%. This highlights the potential of the 30RDI strategy for achieving significant water savings without compromising oil production. Furthermore, the study investigated the impact of water stress on fruit development, leading to the suggestion of a positively improved RDI strategy that involves a total IA of approximately 2,100 cubic meters per hectare (Fernández et al., 2013).

https://doi.org/10.55627/zoobotanica.001.02.0613

Olive Harvesting

Harvesting is undoubtedly a challenging and critical task in agriculture. The motivation behind the drive for mechanization in this field is influenced by several factors, including the rising costs of labor, labor shortages, and the imperative to enhance efficiency. One key aspect of this issue is the gradual mechanization progress. This is primarily because agriculture encompasses diverse and unstructured environments, making it a complex task to design machines capable of efficiently and delicately harvesting various crops, Semi-automatic harvesters have been introduced to assist in harvesting activities. These machines often require some level of human involvement and supervision. However, a challenge associated with them is the relatively high risk of damaging the produce. They are typically used in situations where human labor remains a crucial part of the harvesting process. These platforms can significantly reduce the physical strain on workers and boost productivity. Efforts are ongoing to further enhance the mechanization of harvest operations such as continuous research and development aiming to improve the technology used in harvesters and robots. This includes advancements in machine learning and computer vision, which can enhance machines' ability to identify and handle crops with care. The high cost of fully autonomous harvest robots has been a barrier to their widespread use. Initiatives are underway to make these technologies more economically accessible to farmers, potentially driving broader adoption (Zhang et al., 2016).

Mechanical harvesting of olives is performed by hand-held harvesting equipment that separates the fruit through vibration produced by an electric motor or an engine. These machines can harvest more than 80% of the total mass of olives available on each tree in 5 minutes, but the performance of these machines is affected by different factors related to the mechanical features of the machine and the features of the variety of the tree (Aiello et al., 2019).

Figure 7. Hand-held olive harvesting.

Table olive harvesting is traditionally reliant on manual labor, which can be labor-intensive and potentially affect yield. The introduction of mechanical harvest systems has led to a comprehensive evaluation of the entire process. Two types of harvesters, namely the canopy shaker harvester and the tree trunk shaker, have been utilized and tested for their suitability in the mechanical harvesting of table olives. A canopyshaker harvester requires a specific layout and arrangement of tree canopies to achieve an acceptable harvesting efficiency, of approximately 80%. It offers a relatively high efficiency in harvesting olives. The tree trunk shaker system boasts even higher efficiency, around 95%. However, it remains dependent on manual labor for its operation. Both mechanical harvesting systems exhibit a high field capacity, with an approximate rate of 0.15 hectares per hour. Nevertheless, it's essential to acknowledge that each system comes with its own set of advantages and disadvantages. Orchard adaptation and operational considerations are crucial for the successful implementation of these systems (Sola-Guirado et al., 2020).

In the globalized market, even countries with long-standing traditions in olive cultivation are compelled to embrace the latest and most dynamic methods in olive farming to reduce production costs, especially in labor-intensive operations like harvesting. One notable innovation in olive cultivation is the adoption of the "super intensive" model. This approach offers a significant advantage, primarily centered on highly efficient mechanized harvesting operations, which are carried out seamlessly using modified equipment capable of handling olives. This shift towards mechanization not only enhances efficiency but also contributes to the competitiveness of these countries in the global olive market (Giametta and Bernardi, 2010).

Olive cultivation is associated with substantial production costs, particularly during the harvesting phase. Harvesting techniques encompass a wide spectrum, ranging from manual labour to basic handheld equipment, and up to fully mechanized systems. The choice of method depends on various factors including economic, technical, and social considerations. To address this diversity in crop conditions, three primary scenarios for olive oil production were identified, categorized by the level of mechanization and the cropping system. This study provides insights into the costs and technical aspects associated with these three levels of mechanization for olive oil harvesting. From an economic standpoint, manual harvesting incurs costs of approximately €3300 per hectare. The use of handheld equipment reduces costs by 40-48%, employing trunk-shakers with ground nets results in cost reductions ranging from 59-72%, trunk-shakers equipped with collecting umbrellas lead to even greater cost savings, in the range of 68-80%, straddle harvesters offer the highest level of cost-efficiency, with reductions reaching 85-90%. Consequently, the cost of producing olive oil varies significantly, ranging from €4.7-€2.7 per kilogram with manual harvesting, down to €0.3-€0.5 per kilogram with the straddle harvester (Sperandio et al., 2017).

Numerous trials have been conducted to compare the efficiency of fruit removal and work productivity among these harvesting systems. The results consistently indicate that work productivity experiences a significant boost when mechanization systems are put into action, and this increase is directly proportional to the mechanization system power. For example, the adoption of hand-held shakers leads to a doubling of work productivity when compared to manual harvesting. However, it is essential to note that hand-held shakers are most appropriate for inclined or terraced terrain and smaller farms. In high-density orchards, typically hosting 200-300 trees per hectare, trunk shaker systems have also undergone testing. The results clearly illustrate that the utilization of trunk shaker machines substantially enhances work productivity. The amount of development varies based on the specific interceptor systems employed, which can range from nets to reverse umbrellas. The findings from these tests highlight the universal benefits of employing mechanization systems for olive harvesting. These systems effectively reduce production costs and elevate work productivity, ultimately enhancing the competitiveness of olive producers in the global market (Amirante et al., 2012).

Traditional olive growing systems have a fundamental role in the landscape and environmental safety. A special olive picking module has been developed with picking equipment: the “rotating comb” driven by a common digger. Harvest productivity reached an average time of 14-17 min/plant, which is almost 50% of that obtained with similar combing equipment. Results have been referred to specific “olive tree indexes” to better compare productivity in plants of different dimensions (Vieri, 2002).

The transition from traditional hand-harvested olive plantations, typically consisting of 70-100 trees per hectare, to high-density orchards with mechanized harvesting methods is a notable trend in olive cultivation. The timing of fruit production and the overall productivity are directly correlated with plant density. Additionally, the interception of sunlight by the canopy plays a vital role in determining productivity and oil yield. In hedgerow systems with continuous canopies, the relationship between canopy cover and light interception is influenced by factors such as row spacing, orientation, and canopy permeability to incident radiation. The successful management of high-density orchards necessitates careful consideration of various factors, including the choice of olive cultivar, irrigation practices, orchard design, training and pruning techniques, and overall orchard management. Maintaining the ideal canopy size and shape is crucial for efficient light interception and facilitating easy access for harvesting systems (Rallo et al., 2013).

The relationship between olive tree density and yield indicates that higher tree densities tend to result in better yields, although this advantage comes at the expense of increased time required for harvesting operations. Furthermore, as olive groves age, there is often a decline in yield observed in higher-density plantations due to reduced levels of sunlight reaching the trees. The presence of relatively short rows, averaging around 42 meters in length, has had a detrimental impact on harvester efficiency. This is primarily due to the extended accessory times required when dealing with shorter rows, which in turn hampers the overall efficiency of the harvesting process. This approach involves elongating the rows and addressing logistical issues such as narrow dirt lanes, inadequate road systems, and steep slopes. Implementing these changes makes it possible to achieve significant improvements in harvester efficiency, ultimately optimizing the harvesting process in high-density olive plantations (Bernardi et al., 2008).

Figure 8. Olive canopy shaker.

Harvesting has emerged as a critical bottleneck in the olive oil industry, and the scarcity of agricultural labor is the driving force behind the quest for mechanized solutions. A comprehensive evaluation of the efficiency of three mechanical olive-harvesting systems and methods was conducted over two seasons. This assessment aimed to provide a balanced understanding of their respective advantages and limitations. Unfortunately, none of the trunk shakers and their associated harvesting methods were found to be sufficiently efficient to eliminate the need for manual labour. Consequently, there was still a requirement for a certain number of workers to manually strike the branches with sticks to facilitate the harvesting process. Moreover, vine harvesters, typically utilized for olive harvesting, were observed to leave notable quantities of olives on the trees, highlighting their limitations in achieving full fruit retrieval. The two-stage approach holds promise as a means to enhance the efficiency of olive harvesting, ensuring a more comprehensive and effective orchard harvest (Zion et al., 2011).

Manual olive harvesting is known to be one of the most expensive and labour-intensive operations in table olive production. However, the adoption of electric hand-guided machines has the potential to significantly increase productivity, often tripling the output. The development and integration of these innovative machines are reshaping harvesting methodologies and altering the way operators perform their tasks. This observation emphasizes the importance of understanding and managing hand-arm vibration levels to safeguard the well-being of operators when utilizing electric hand-guided machines for olive harvesting (Deboli et al., 2014).

Conventional olive orchards, typically characterized by lower planting densities of 80 to 100 trees per hectare (ha), tend to have relatively low productivity and associated high crop costs, including expenses related to harvesting and pruning. Since the 1970s, agricultural experts have recommended transitioning to higher planting densities, referred to as the intensive system, which involves approximately 200-500 trees/ha. This approach is designed to facilitate efficient harvesting through the use of trunk shakers, ultimately resulting in increased yields and more manageable production costs. In the early 1990s, a novel type of olive orchard known as the super-high density hedgerow system emerged in Catalonia, located in north-eastern Spain. To improve the efficacy of mechanical harvesting, effective management of tree vigour is essential. This ensures that tree size remains within manageable limits while maintaining high levels of productivity (Tous et al., 2010).

The traditional practice of table olive harvesting has historically relied upon manual labour. However, due to challenges such as labour shortages and the associated high costs, the agricultural sector has been actively exploring mechanical alternatives. This study evaluated and compared the efficacy and product quality of mechanical harvesting to manual picking for four distinct green table olive cultivars: Manzanilla, Hojiblanca, Souri, and Nabali Mouhassan.

Figure 9. Rope tree shaker.

The mechanical harvesting methods evaluated included tree trunk shaking, both with and without continuous rod beating. The study findings demonstrated that when trunk shaking was combined with rod beating, it resulted in notably high harvest efficiencies, ranging from 80% to 95%. Conversely, when the rod-beating component was omitted, there was a significant reduction in harvest efficiency. However, for the Manzanilla variety, the quality of the mechanically harvested olives was found to be inferior to those harvested manually. The utilization of trunk shakers in conjunction with simultaneous rod beating has the potential to achieve high harvest efficiencies. It is worth mentioning here that the quality of mechanically harvested olives may vary depending on the specific olive variety under consideration (Zipori et al., 2014).

Olive Processing

In the field of olive oil extraction, recent scientific research has been focused on improving the quality of the extraction process, with a particular emphasis on enhancing efficiency and reducing processing time. One area of exploration involves optimizing the traditional malaxation process to achieve positive effects on both oil production and consumption. To this end, emerging technologies such as microwave (MW), pulsed electric field (PEF), and ultrasound (US) have been integrated into the conventional virgin olive oil extraction process. The conventional method for obtaining extra virgin olive oil (EVOO) comprises three primary phases: crushing, malaxation, and centrifugation. After olive fruits are washed, they undergo crushing using equipment like stone mills, hammers, disc crushers, de-stoning machines, or blades. During malaxation, this ratio increases to 80% as larger-diameter oil droplets form from the initially smaller ones. Both crushing and malaxation are pivotal steps that significantly influence the quality and yield of the oil (Yüksel Aydar, 2019).

Figure 10. Olive oil extractor.

Producing high-quality olive oil presents a significant challenge, to cultivating olive fruit with exceptional properties, and ensuring the transfer of these positive attributes to the oil is essential for maintaining consistently high-quality olive oil. Additionally, olive processing parameters can be adjusted to optimize oil production tailored to specific fruit characteristics. The primary benefits of incorporating macerating enzymes into the olive oil extraction process comprise, enhanced extraction efficiency in which enzymes can increase oil extraction yields by up to 2 kg of oil per 100 kg of olives, especially when employed in cold processing conditions, improved centrifugal fractionation is that enzymatic treatment leads to improved separation of the oily must during centrifugation, higher antioxidant and Vitamin E Levels is that enzyme-assisted extraction results in olive oil with elevated levels of antioxidants and vitamin E, contributing to improved oil quality and health benefits, delayed rancidity which is the use of enzymes can slow down the onset of rancidity in the extracted oil, extending its shelf life, enhanced overall plant efficiency which is enzymatic treatment improves the overall efficiency of the olive oil extraction process and reduced oil content in wastewater (Chiacchierini et al., 2007).

In recent years, malaxation has gained recognition as one of the pivotal stages in the mechanical extraction process of virgin olive oil (VOO). Consequently, the design of malaxing machines has evolved significantly, driven by a wealth of scientific studies published over the last two decades. These studies have been instrumental in probing this critical phase and its profound impact on the quality of VOO. Key malaxation parameters, including time, temperature, and the atmosphere in interaction with the olive paste, can considerably affect the activity of enzymes accountable for imparting the health benefits and organoleptic potentials to the final product (Clodoveo, 2012).

The current methods for mechanically extracting virgin olive oil from olives can be categorized into two primary types: discontinuous systems, which are becoming less common, and continuous systems. Continuous systems typically consist of three main components: a mechanical crusher, a malaxer, and a horizontal-axis centrifugal separator, also known as a decanter. The term "continuous" refers to the fact that two of these machines, the mechanical crusher, and the decanter, operate continuously, while the malaxer, which operates in batches, is positioned between these continuous components. Consequently, malaxation represents a difficult procedure in the continuous extraction process. Recent years have witnessed significant progress in the application of emerging technologies in food processing, including the VOO extraction process. These emerging technologies include ultrasounds (US), microwaves (MW), and pulsed electric fields (PEF), all of which have been applied in pilot-scale plants for VOO extraction (Clodoveo, 2013).

CONCLUSION

Adoption of olive mechanization reduces problems of labor shortage making the different stages (from planting to post-harvest processing) of olive cultivation easier and cost-effective. This will ensure more area under olive cultivation which may result in optimized both farm productivity and farmer profit. This will improve the per capita availability of olive oil as well as table olives without applying additional manpower. To increase the farm productivity R&D activities should be started and capacity building of agricultural graduates, extension workers, and olive cultivators should be commenced. Generally, in Pakistan, an optimum level of mechanization has been achieved, which results in increased farm productivity and profit. However, mechanization techniques for optimum olive harvesting and processing are not available. To reduce pre and post-harvesting losses and to increase yield, mechanized harvesting operations and post-harvest processing as well as value addition should be adopted for the supply of this value-added product in national and international markets.

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ACKNOWLEDGEMENT

We extend our genuine gratitude to all the authors whose works have been cited in this article, as they have provided the foundational information upon which this research is constructed. We also wish to acknowledge the appreciated contributions of our colleagues and peers who have provided insightful discussions, feedback, and support throughout the writing process. Additionally, we appreciate the contributions of all the contributors for their assistance in analysis, and manuscript preparation, which have significantly contributed to the completion of this paper. We are grateful to all individuals who have played a part in shaping this review paper and for their dedication to advancing knowledge in this field.

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