Olive harvester based on canopy shaker to traditional trees

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Abstract

Spain is the biggest producer country of olive oil in the world. 70% of the total olive growing area is represented by traditional olive orchards and it is required to make them as profitable as modern high density orchards. Mechanisation of harvesting labors is a key factor in reducing olive growing costs. There are no a solution for the integral harvesting of traditional orchards, so the introduction of a harvester may represent a technological change for the improvement of their competitiveness, together with a tree training to the harvester in order to get high fruit detachment rates.

Several prototypes of a harvester componets (a canopy shaker head, a catch frame and a driven system) have been studied in previuos research showing the feasibility for integral harvesting of multi-trunk trees. As a consequence of the Mecaolivar project, these components have been improved and inserted in a harvester conceptual design, according to geometrical parameters of the orchards obtained with photogrammetry techniques. First tests have been carried out in two traditional orchards with different olive cultivar (Picual and Hojiblanca) in 2015-2016 harvesting season. Results provided removal efficiency over 88 %, harvest efficiency over 76 %, low debris production and an effective field capacity of 0,21 ha h^{-1}. Results demonstrate the viability of integral mechanical harvesting for traditional olive orchards and the ongoing on a viable harvester development.

Keywords: Olive oil, traditional orchard, canopy shaker, harvester, development

1. Introduction

The olive oil industry has a outstaning importance all over the world producing an annual revenue over € 10 billion (IOCC, 2016). In Spain, the main producer country, more than 74% of the olive orchards are trained with a traditional configuration, planted at very large spacing (30-180 tree ha^{1}), low orchard yield (1.1-4.5 t ha^{-1}), with several trunks and big sized canopies (Pergola et al., 2013). In this orchard category the growing costs are too high, reducing or eliminating their orchard profitability (AEMO, 2012).

Harvesting labor may represent more than 40 % of the total growing costs being the most difficult operation due to the complex structure and geometry of those trees. Current commercial systems for the harvesting rely on some technical solutions highly conditioned by manual labor requirements. The most extended harvesting procedure could be separated into two pahses: Firstly, fruit detachment can be performed manually or using mechanical methods, where fruits are fallen on nets or directly to the soils; Afterwards, fruits are loaded to an in-field trailer (Gil-Ribes et al., 2008). The introduction of an integral harvesting system may be a key factor for solving social and work issues because might supply the lack of labor and lighten some operation, reducing labor requirements, costs and harvesting time (IOC, 2007).

In recent years, mechanical harvesting based on trunk shakers have been intensively developed although they have limiting factors such as multi-runk tree training and power limitations of the tractors used. Most recently, straddle canopy shaker based on vine-type harvesters have been introduced for olive harvesting but this new technology requires adapted tress with high-density configuration (Ravetti and Robbs, 2010). Lateral canopy shakers may prove suitable for traditional olive trees making possible an integral mechanical harvesting. These sytems perform fruits detachment using vibrating rods that come in contact with the canopy making possible to catch the detached fruits (Gil-Ribes et al. 2011). The wide spacing between trees may enable relatively high harvest efficiency values in a harvesting process around the tree canopy (Sola-Guirado et al., 2014), although it is necessary a tree adaptation.

A harvester based on canopy shaker for traditional olive orchards should be developed to enhance farm profitability. For that purpose, it is necessary a long process of research, develop and test, just like it has been carried out by other machinery such trunk shakers (Tous, 2011). The design of an effective harvester should satisfy several requirements. Firstly, the canopy shaker must perform an effective detaching fruit process with a right motion, amplitude and frequency. Detached fruits must follow vertical fall enabling simultaneous collecting. Morever, the harvester must allow a continuous shaking process avoiding severe damages with the closest contact with the tree canopy. Shaker heads should move around tree canopy adapting their position to the canopy irregularities. Finally, harvester dimensions must be adapted to tree and driven system must perform an adecuated maneouvrability.

To meet the requirements, it is necessary to obtain tree geometrical features. It is possible to measure trees using several methods, although the most common used are manual measurements. However, these methods may be very inaccurate. Another option is to take measurements based on electronic devices such as ultrasound sensors, digital photographic techniques, stereo vision sensors and LIDAR (Rosell and Sanz, 2011). Aerial information is also highly useful. It could be obtained from satellites or from airborne platforms although the last ones are very promising because of the low cost and high accuracy. In this way, photogrametry is a technique that may give valuable information to characterize orchards from ground and aerial images.

The main purpose of this work is to demonstrate the viability of the integral harvesting traditional olive orchards using a harvester based on canopy shaking. For that purpose, geometrical parameters of traditional olive trees have been obtained. These canopy measurements and previous knowledge adquired during previous canopy shakers tests have been used to develop a lateral canopy shaker for integral olive harvesting.

2. Materials and Methods

2.1. Trees description for harvester design criteria

Two spanish traditional olive orchards located in Córdoba (Hojiblanca cultivar) and Jaén (Picual cultivar), and managed under deficit irrigation (below 1000 m^3 $year^{-1}$) were selected for tests. Images from 48 trees of each orchard were taken at ground level and from orthoimages obtained with an UAS. Several geometrical parameters were obtained from the processed images (Figure 1). They are useful for the harvester design process according to the orchard features. Tree aerial contour was obtained from orthoimages and they were fit to regular geometries (circle, elipse and rectangle) according to the igualation of their aereas using the software Image J with imaging particle analysis (Abramoff et al., 2004).

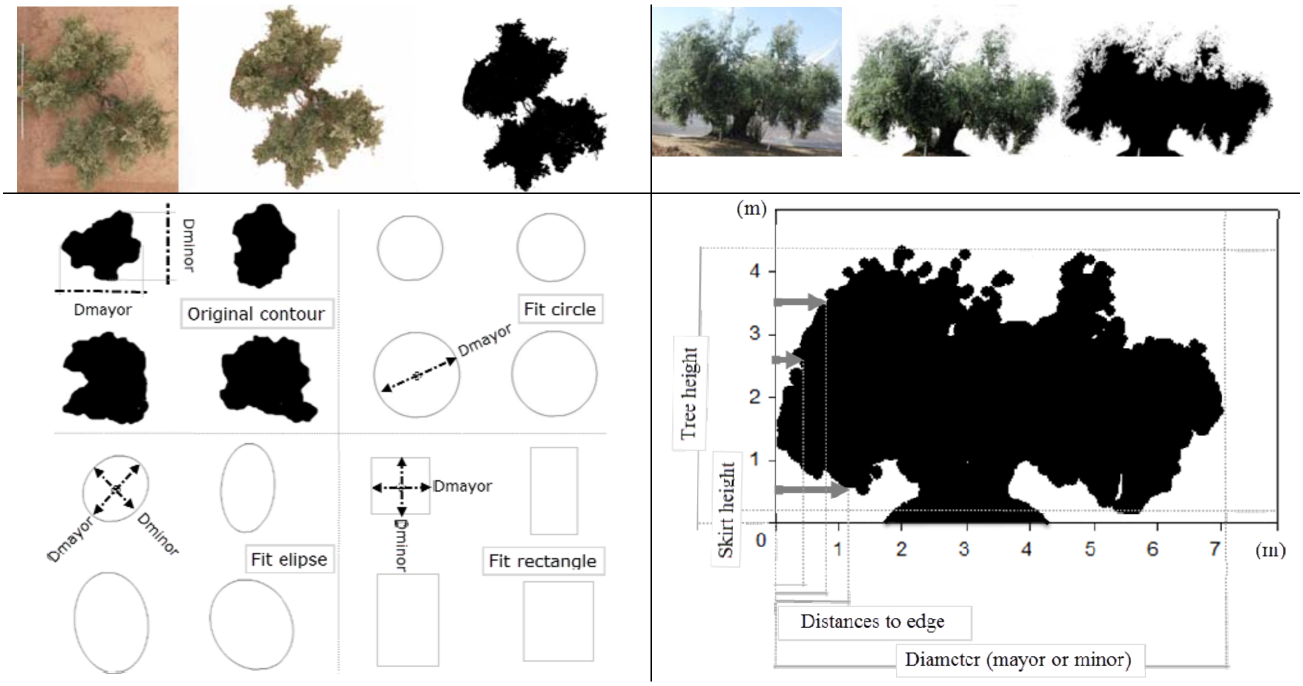

Figure 1. Particules analysis of processed aerial (A) and ground (B) images

Images at ground level were acquired using a digital camera (Sony Nex7, Japan) with an aperture of 3.6, a focal length of 18 mm and an ISO velocity index of 100, without a flash on windless days between 12-14:00 pm, and located 1.8 m above the ground. A white plastic background was set behind trees to aid the image processing.

Aerial images were acquired with the same camera located on an UAS (DJI S800 and WOOKONG-M, China) fully autonomous operated using waypoint navigation guidance for automatic image acquisition. The flight plan was set at a height of 90 m above ground, 8 m s^{-1} speed, and setting a longitudinal and transversal overlap of 85 and 70%, respectively, to cover the entire target area. The imagery was synchronized using a GPS and a triggering time was recorded for each image. The pictures obtained enabled the generation of the orthoimages from the orchards using an specific software (Pix4D, Ecublens).

Image processing was performed manually by an expert trained for this purpose. In the first stage, the original images were transformed into gray-scale to create a monochromatic image for digital image processing (Clement et al., 2012). Afterwards, it was determined two thresholds in the gray scale image that would allow distinguish the tree contour, associating the Green band brighter with the background (Meyer and Neto, 2008) and using R-values ranging from 0 to 255 for each image. Finally, it was obtained a binary image of each particle using the pixels of each tree contour for the particle analysis (Igathinathane et al., 2008) and converting pixels on m^2.

2.2. Components of the harvester

The harvester was composed by a removal system based on canopy shaking, a catch frame to receive and manage the detached fruits and a driven system which supports the removal system and the catch frame (Figure 2). The design of the canopy shaker and the catch frame was evolved from the prototypes tested by Blanco-Roldán et al. (2014) and by Sola-Guirado et al. (2013), respectively. Previous to the driven system, a prototype had been developed by Sola-Guirado et al. (2016) and tested obtaining usefull data to get an adequate design that allow a right maneovrability around the tree. Finally, these three systems were redesigned by parametric design software (SolidWork ®) according to tree features obtained and adapted to their placing in a conceptual harvester design that was manufactured.

Figure 2. Previous experimental prototypes tested for their integration in final harvester

2.3. Evaluation of the prototype

The final designed harvester was manufactured, being tested in 60 traditional olive trees of the two evaluated orchards on the 7-17th December and 11-21th January of 2015 and 2016. Mean fruit detachment force (FRF) were 3.65 and 2.25 N, in Hojiblanca and Picual cultivars respectively. The operating parameters set in the harvester were 0.8 km h^{-1} ground speed, 5 Hz shaking frequency, and 0.16 m amplitude. The harvester followed a round path around trees keeping the shaking heads as closer as possible to the canopy contour. The removal efficiency was evaluated weighting the detached fruits by the prototype and the remaining ones on the tree, separating fruits from the inner and outer canopy volume. For this purpose, outer canopy volume has been considered as the canopy branches which were at 1.5 m depth from the canopy surface in the volumen where the rods made an effective contact. Harvest efficiency was evaluated weighting the detached fruits intercepted by the catch frame and those that fell down to the ground. Debris produced by the harvesting process was weighted and separated into two groups according to branch diameter: minor debris (between 2 and 25 mm) and major debris (>25 mm).

3. Results and Discussion

3.1. Tree features

Aerial imagery determined that tree spacing was nearly an square for Picual orchard (11.4 ± 0.8) while the other Hojiblanca orchard showed a quincunx layout (9.8 ± 1.1 m). The square spaced orchard provide a 3 ± 2º angle deviation between rows and the quincunx spaced orchard had 58 ± 6º row angle between both row directions. Tree mean diameters measured by ground images were 6.4 ± 0.9 m for major and 5.3 ± 0.9 m for minor diameter while the mean diameters measured by aerial images were a little bit larger (6.8 ± 1.5 and 6.0 ± 1.1). The differences obtained may be due to the image processing or the camera lens angle. The mean tree heigh and skirt heigh was 3.9 ± 0.4 m and 0.5 ± 0.1 m, respectively. The mean distances to edge of the canopy height between 0.5 to 4 m from the ground are 1.3 ± 1.3 m.

The parameters of fit geometries on the original contourns of trees are displayed in Table 1. Original contour were very irregular on their silhoutes and shown big differences between trees. The mean diameter of fit circle was similar to the mean diameter obtained from the original contour of the ground and aerial images, being this geometry the most appropriate to a right path of harvesting around the tree.

Table 1. Geometrical parameters of traditional orchards according to fit geometries on the original contourn. Values shown mean ± standard desviation

Contour	Parameter	
Original	Area (m^2)	29.3 ± 6.8
	D mayor (m)	6.8 ± 1.5
	D minor (m)	6.0 ± 1.2
Fit circle	D mayor (m)	6.2 ± 0.8
Fit elipse	D mayor (m)	6.8 ± 1,0
	D minor (m)	5.1 ± 0.8
Fit rectangle	D mayor (m)	5.9 ± 1.1
	D minor (m)	5.3 ± 0.9

3.1.1. Harvester design criteria

- Harvester dimension

Taking the consideration there are trees with canopies larger of 8 m and mean tree spacing of 11, the nearest branches between trees are about 3 m distanced, that is the available space for moving around trees without breaking branches, so the harvester width must be less that this dimension. The canopy shaker should reach the maximum tree heigh, although it can be limited to 3.6 to ease the road transport of the harvester and keep down the machine center of gravity. On the other hand the canopy shaker should reach the minimum heigh skirt, although it can be raisen about 1 m from the ground to facilitate the incorporation of a catch frame.

It is wanted to perform an eliptical path around tree canopy. The differences between mean diameters indicate that the driven system may allow righting the radius path about 0.75 m.

- Canopy shaker configuration

The shaker rods should penetrate about 3 m according the mean diameter of trees (6.3 m) although it could be reduced to 2.5 m because of the inner tree volume of 1 m of diameter have not a significative quantity of fruits. Moreover it is possible to press the canopy about 0.5 m, reducing rod penetration to 2 m. Therefore, the canopy shaker rods should have a lengh of 1.4 m due to acceleration transmission rate in traditional olive trees is about 40 % (Gil-Ribes et al., 2011).

Large differences in the canopy distances to the edge indicated that the shaker heads should change their position in order to be as close as possible to the canopy. In this sense, the approaching to the canopy should be performed by several shaker heads instead only one (Figure 3) to copy the tree silhouete. 4 heads were used for shaking an useful canopy volume between 1 and 3.6 m above ground, based on the shaker head design obtained by Blanco-Roldán et al. (2014) with a separating rods 0.4 m. Each head was positioned by a hydraulic cilinder which made it able to approach the tree canopy depending on crown shape. Maximum approaching distance was 1.3 m, according to the maximum distantce to edge measured in the traditional olive trees contour.

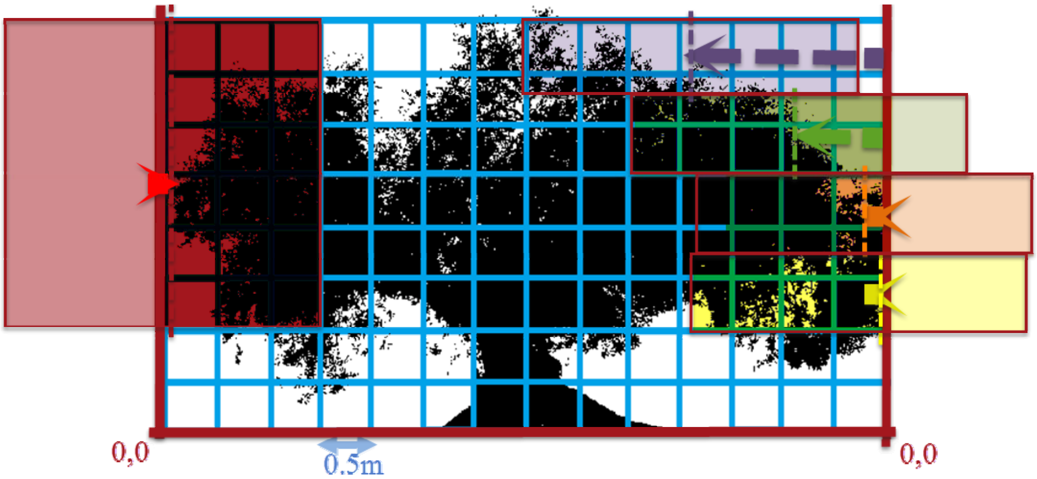

Figure 3. Traditional olive tree contour and representation of copy the lateral contour with a single (left) or four shaker heads (right)

- Pruning recommendation

It is required that trees were trained to the harvester elevating the skirt height and reducing the tree size.

Moreover, it is neccesary a pruning system that enlarge outer branches yield eliminating the inner bearing branches. Finally, when the harvester worked around tree canopies, regular geometries nearby a circle were needed to increase the contact time between the harvester and tree canopy. As a consequence, it is necessary adapting tree progressively to not decrease orchard yields during the seasons (Muñoz-Cobo, 1988).

3.2. Development of the harvester

3.2.1. Redesign of the driven system

The catch frame is located on the chassis which have a vertical column where the cantilevers that supported shaker heads are clutched. (Figure 4). It incorporates a leveling system that can operate manually or automaticaly by an inclinometer sensor. This sytem is composed by two axles located in the back and in the front part of the frame that were able to pivot 12º each side. A tractor pull the harvester by a bar that may displace 0.8 m the moving forward direction of the trailed harvester from the tractor forward direction. The driven system was equiped also with selfturning wheels in the front axe while the rear axe was controlled by two steering wheels.

3.2.2. Redesign of the catch frame

The catch frame (Figure 4) have several conveyors that drive fruits and debris to a lateral of the harvester where are separated. Then, in this gather place, fruits go to another conveyor that transport them to the rear part. Where are stored in a big bag of about 500 kg. The structure underneath the tree has several spring-loaded catching plates which brush against tree trunk and deflect fallen fruit to the conveyors.

3.2.3. Redesign of the canopy shaker heads

The main modifications performed on the first shaker head prototype (Figure 2) have been to reduce the vertical distances between drums, to equilibrate the mechanism by the incorporation of counterweight, and the optimization of the drums and the structure to approach the shaker heads to tree canopies. The shaker head device (Figure 4) is attached to the cantilevers which can pivot horizontally. This movement allowed the shaker heads approach to the tree canopy 1.3 m. The shaking mechanism is composed by an axle spindle with two masses with an eccentricity of 80 mm and offset 180º where were located drums with 15 metal rods of 1.4 m. The axle actuated by a hydraulic engine that can spin from 120 to 37.7 rad s^{-1}. Drums may rotate freely for better adaption to tree canopies during harvesting process around trees without producing damages. Rods perform a rotational and crossed motion that hit tree branches.

3.2.4. Integration of the components

All components were integrated in a harvester. The mechanisms were powered by a hydraulic power unit located in the tractor. Two drivers were required, one of them to drive the tractor and the harvester path and another one to control the shaker heads approaching to tree.

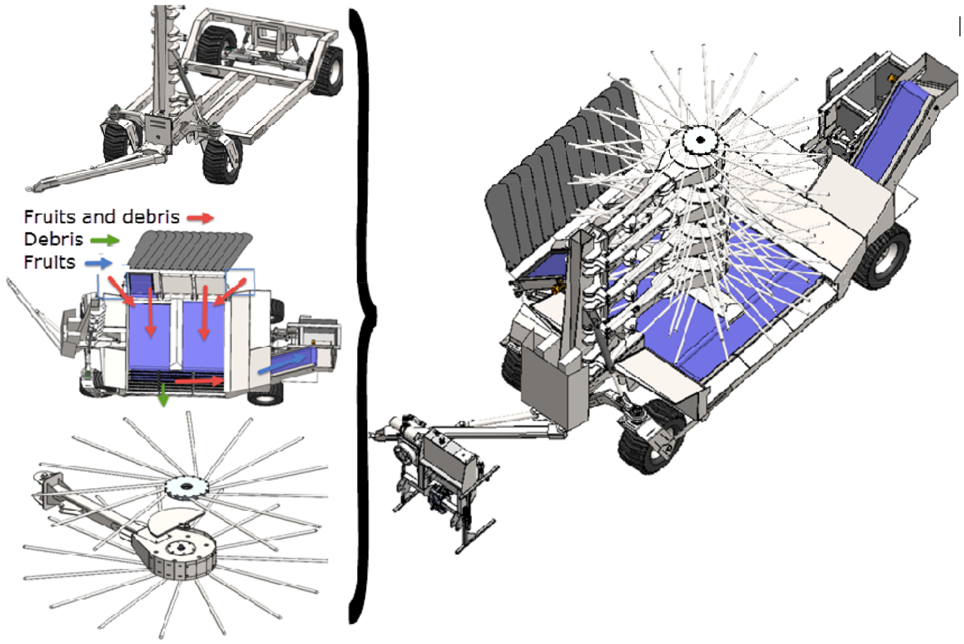

Figure 4. Design of components (driven system, catch frame and canopy shaker head) and integration in a harvester

3.3. Evaluation of the prototype

Removal and harvest efficiency with debris production (Table 2) were assessed in the orchards with satisfactory results (Figure 5).

Figure 5. Harvester working around a traditional olive tree

Table 2. Evaluation of parameters performed by the harvester prototype on traditional olive orchards. Values shown mean ± standard desviation

Cultivar	Fruit Detachment Force (FDF) (N)	Removal efficiency (%)		Harvest efficiency (%)		Debris production (kg)	
		Outer	*Global*	*Outer*	*Global*	*Small*	*Large*
Hojiblanca	3.7 ± 1.3	88 ± 12	80 ± 14	78 ± 16	69 ± 13	4.2 ± 2.3	1.5 ± 3.2
Picual	2.2 ± 0.9	97 ± 1	88 ± 6	77 ± 10	68 ± 10	6.9 ± 4.5	0.5± 0.5

The canopy shaker performed an adequate removal efficency in early harvest although lower than late harvest. However, significant differences ($\rho<0.05$) had been found between cultivars for removal efficiency while no differences have been found in harvest efficiency. Differences on removal efficiency may be due to 'Hojiblanca' cultivar has very few lateral branching while 'Picual' produced more lateral shoots showing more compact canopy architecture which favour a rounded canopy contour. This rounded structure was more adequated for circular harvesting path to enhance the contact between the shaker heads and tree canopy. Moreover, the manual approaching of 4 heads difficulted to mantain an optimum contact with canopy during the continuous harvesting process. The major part of non detached fruits on the outer canopy volume was located on skirt branches due to minimum height of shaker rods was 1 m being with the mean skirt heigh of 0.48 m. In addition, upper branches over the maximum heigh of rods had also non detached fruits. Inner fruits represent from 8 to 9 % of total amount of fruits which were out of reach for the shaker rods. As a consecuence, it is remarkable the importance of tree training focused on canopy shaking. On the one hand, canopy shaker targeted pruning must tend to reduce inner branches, limiting the tree and skirt height and enforcing a rounded canopy contour to improve the removal efficiency. On the other hand, an automatic control system should be developed to control the shaker heads approach to the canopy. Both improvements for tree training and shaking heads control will enhance the harvester performance.

The catch frame system attained to intercept the detached fruits although a remarkable quantity of them felt on the ground. The most losses in the catch frame were located on the front part beside the tree due to skirt branches brushing against the catch frame system. The losses in this part were bigger in 'Picual' where fruit detachment force (FDF) was lower. This may also be due to there less time to detach fruit so fruits fall dawn before catch frame arrive to collect them. These facts strongly suggest enlarge the interception surface to get a competitive harvester. Also, it would be advisable to increase the closure plate inclination to avoid rebounds of detached fruits to the ground.

Results of debris production were in line with those caused by other available harvesting systems (Sola-Guirado et al., 2014). Small debris should be reduced by the addition of padding material in the shaker head and rods (Castro-Garcia et al., 2009). Most large debris is due to broken branches by the shaker during the harvesting path around the tree mainly in trees with sharped irregular canopies.Tree training should reduce debris production by having more rounded canopies.

The mean time for a tree harvesting was about 210 ± 22 s, so the work cappacity was 0.22 ± 0.02 ha h^{-1} in a orchard layout of 80 trees ha^{-1}, with two workers. Results are lower than other lateral canopy shaker (Castillo-Ruiz et al., 2015) because of the big sized canopies and the difficulties in harvester maneuovrability that force the harvester to limit ground speed. However, the prototype is the first harvester that allow integral harvesting in multi trunk traditional trees with two operators, being highly cost competitive with the current commercial harvesting systems.

Finally, primary results encourage improving the prototype in order to achieve a commercial harvester. This upgrade process should undertake two improvement fields: an adapted tree training system for traditional olive orchards and canopy shaker adaption and automation to get better results. The introduction of such innovative harvesting method requires an extra effort taking into account that traditional olive growing is one of the world's oldest tree crops with a resistant to change culture. Besides, the focus of mechanical harvesting on traditional orchards must be dual: developing successful harvester for adapted trees with a simultaneous input of researchers, machinery manufacturers and farmers. The only way to keep the profitability thresholds for traditional olive orchards is to achieve an integral mechanized system that improve the growing costs and achieve a hight effective field capacity. It is important to keep in mind that olive growing maintains the main economic activity in large areas of the Mediterranean basin.

4. Conclusions

Different methodologies to characterize olive orchards and trees have been established providing quick and inexpensive methods that give an extra knowledge to design machinery adapted to tree size and shape. Trees are not adapted to canopy shaking due to irregular canopies and limited skirt height.

A new canopy shaker harvester has been designed to carry out an integral harvesting process in traditional olive trees in order to enhance oil quality and reduce the production costs. Primary tests demonstrate the technical and economic viability of integral mechanical harvesting in traditional olive orchards and now, it is an ongoing process to pursue the limiting factors of trees and prototype.

To sum up, the advances and solutions achieved to harvesting traditional olive trees, will make this olive orchard category as competitive as other growing system.

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