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Evaluation of a manual olive fruit harvester for small producers

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Abstract: Harvest facilities limit the possibilities of small producers to produce a high-quality olive fruit. This paper discusses the efficiency of a newly designed manual picking device as a possible solution to these specific challenges as confronted in most regions of the Mediterranean basis. The efficiency and cost of the picking method were compared to traditional olive picking using nets, taking a different number of operators and branch shakers into account.

Keywords: branch-shaker; harvest efficiency; inverted umbrella; *Olea europaea*; family orchard

The production of quality olive oil is highly conditioned by the way the olive fruit is harvested (Saglam et al. 2014), but it is also related to the cost. Therefore, full or partial mechanisation is highly recommended (AEMO 2012). Yet, for small producers, the use of specialised machinery very often implies an insurmountable investment and the difficult short-term amortisation (Serrano-Castillo et al. 2012). Spain stands out as the major producer of olive oil with more than 2.5×10^6 ha of cultivated area. However, the characteristics and the distribution show a huge fragmentation. In Andalusia, which is the most prominent production region by far with 60.2%, with between 15 and 20 million labour days a year (Ministerio de Agricultura y Pesca, Alimentación y Medio Ambiente, 2014, 2017), 72% of the olive groves contain less than 200 trees per ha (Junta de Andalucía, 2015) and 80% of them are less than 10 ha (Junta de Andalucía, 2009), concentrating about 60% of the national production, (Ministerio de Agricultura y Pesca, Alimentación y Medio Ambiente, 2014). For this reason, the use of manual picking methods (manual beating, shaker combs or branch shakers) is currently widespread with nets placed under the trees and on the ground to catch the detached fruit.

The optimisation of the interception and the handling of the picked fruit has long since been the subject of many ingenious inventions, including platforms (Johnson, Robbins 1919), folding (Cook 1923) or rotating devices (Langford 1944), some of them equipped with a sophisticated conduction system for the picked fruit (Leighton 1952). These inventions lingered into the background because of the development of new machinery that requires less labour. However, the efficiency of these machines requires a significant economic investment that many producers cannot afford. For this large

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group of farmers, new models have been presented recently for the manual interception of olive fruit, and most of them are based on the use of an inverted umbrella (Bosco, Crendon Machinery, Olitree, etc.). Nevertheless, their use and utility still entail difficulties, such as the large weight, difficult access to the trunks or the handling of the fruit boxes. Throughout the harvest process, several factors affect the quality of the fruit, like the action of pathogens and mechanical damage, especially when the fruits are collected from the ground or are dragged over nets (García, Yousfi 2006; Morales-Sillero, García 2015). This work presents an affordable device for small producers to collect the detached fruit in small boxes without falling on the ground and absorbing the energy of the fall.

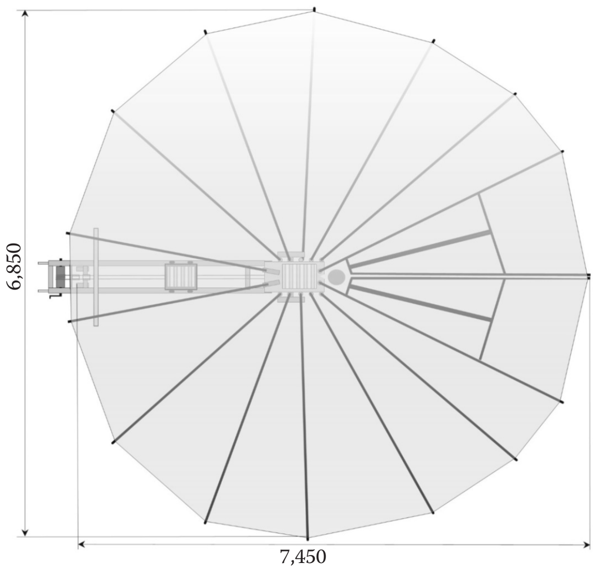

Fig. 2. The Manual Inverted Umbrella (MIU) from the top view

scheme from the top view; measurements are in mm

MATERIAL AND METHODS

The proposed picking method (PM1) is composed of several components: (*i*) A Manual Inverted Umbrella (MIU), designed to catch and collect the olives, preventing them from touching the ground; (*ii*) boxes to store the picked olives; (*iii*) a team of operators, capable of detaching the fruit with branch shakers and handling the MIU and the boxes.

The MIU has an inverted umbrella structure with 14 aluminium bars covered with a resistant canvas (Figs 1 and 2). The maximum opening diameter is 6.85 m; the highest part of the system is located at 1.45 m, which allows the operators to access the tree in order to hook the branch vibrator at the right place. To facilitate this operation, the canvas joins the ribs of the skeleton by rings, while its outer ends are joined with the ribs of the umbrella by an elastic band that moves over a small roller. The system was mounted on a chassis 4.25 m long with 4 wheels for transport and easy movement between the trees. In the centre of the device and coinciding with the position of the trunk of the tree, a space is left uncovered where the fruits roll down by a natural slope and are collected into a plastic bag and perforated box of 20 kg in capacity. This box is introduced and extracted by a system of pulleys and ropes. The MIU allows the capturing of the detached olives by means of a branch vibrator, avoiding any contact with the ground. The prototype proposed was properly used throughout one whole season and compared with the traditional methods used (Show in Electronic Supplementary Material-ESM).

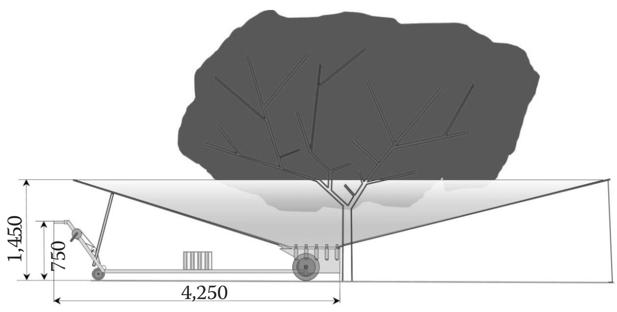

Fig. 1. The Manual Inverted Umbrella (MIU) from the side view

measurements are in mm

The experiment took place in La Puebla de Cazalla (Seville, Spain), in an intensive olive grove (a frame of 7 × 6 m) with 8-year-old trees of the Hojiblanca variety. The results obtained using the proposed device (PM1) were compared with those obtained by the conventional method (PM2), which uses nets arranged on the ground under the trees. Combining the performance of 2 or 3 operators, 1 or 2 vibrators and using both picking methods, resulted in a total of 8 different treatments. Each one was evaluated using experimental units of 3 trees randomly distributed in a row of 24 trees. The experiment was carried out in triplicate, using three rows with a total of 72 trees.

The measured times of the harvest cycle (t_h) comprise the sum of the time spent in the placement of the nets or the MIU below each tree (t_p);

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the detaching of the olives from each tree (t_d) and the loading in the boxes every 3 trees (t_l). The performance of the operation by the crew and each operator was evaluated taking the weight of the fruit collected in each treatment (s/10 kg) into account.

The amount of the detached olives that did not go into the box was counted, regardless of whether it was because they did not enter the inverted umbrella or because they escaped due to a defect in the design of the prototype. The percentage of the interception was calculated according to the (Eq 1.):

$$\text{Percentage of interception}(\%) = \frac{m_a \times 100}{m_a + m_b} \quad (1)$$

where: m_a – weight of the olives in the boxes; m_b– weight of the olives on the ground

The material and labour costs were calculated. The useful life of the equipment and machines used (branch shakers, nets, boxes and MIU) was estimated over 10 years. The value of the MIU was calculated on the actual costs (final material used and total hours of work required for its construction). The labour cost that each treatment requires was based on the official salary table of the field workers (season 2016–2017) (https://agriculturafacil.com/tabla-salarial-del-campo-2016-2017). The costs in €·kg^{-1} of all of them was calculated for each experimental unit by considering the time necessary for picking and the kg of fruit harvested.

A three-way ANOVA (analysis of variance) (SPSS Statistics Software, version 18) was used for simultaneously measuring the effect of the three factors tested on the variables related to the harvesting: the picking method (PM1 and PM2), the number of shakers (1 and 2) and the number of operators (2 and 3). Furthermore, the effect of the 8 treatments, combining the different factors tested, was also studied on the same variables by the one-way ANOVA. When a significant (P < 0.05) effect due to the treatment was detected, Tukey's test was applied to differentiate the mean values (P < 0.05).

RESULTS AND DISCUSSION

The results show that PM2 systematically required less time for its displacement and placement than PM1, showing an extremely significant difference (P < 0.001) (Tables 1 and 2). The use of more workers should have an impact on the acceleration of the placement of harvest methods. However, this fact is only seen systematically in PM1, because the increase in the one operator will always determine the reduction in the installation time of the device by around 40% with this method. However, in PM2, it is remarkable that when the number of operators increases from 2 to 3, it makes a significant difference whether the number of used vibrators also increases from 1 to 2. In the first case, the reduction in time is almost 50%, and as such, even higher than the one presented by PM1, while, when both the number of operators (3) and the use of the vibrators (2) are increased, the reduction in time is practically negligible.

The time-in-use of the branch vibrators was systematically inferior in the treatments that used PM2, which determined that, as a whole, an extremely significant effect was seen due to the collection method (P < 0.000). This difference is due to the fact that the presence of the PM1 device is bothersome for the operator in the use of the vibrator, making it difficult to access all the branches of the tree. However, these differences were not significant among the homologous combinations, which used the same number of operators and vibrators, as seen in Tukey's analysis of the difference in the means of the 4 treatments analysed independently. In the same way, the use of one more vibrator determined that its time of use was systematically reduced, regardless of the picking method and the number of operators, showing, consequently, that this factor exercises an extremely significant effect (P < 0.000). This fact could be expected, as an increase in the amount of machinery must decrease its time being used. However, the increase in the number of workers, although it also presented a systematic time saving factor in each case, did not cause a significant effect (P < 0.245). Neither did the possible interactions among the different factors studied show to be a significant effect.

The loading of the olives into the boxes was only affected by the increase in the number of operators (P < 0.002), which is logical, since the vibrators do not intervene in this process. Although PM1 allows for advancing the filling of the boxes during the use of the vibrators, it did not determine a significant decrease in this period with respect to PM2 (P < 0.356). This fact can be associated with the formation of the bags with fruit in the MIU, which delayed the fall of the olives into the boxes and required the intervention of the operators. This additional act determined that no significant dif-

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Table 1. Time (s) spent in each operation of the harvesting of 10 kg olives

Treatment	Methods	Shakers	Operators	Placing	Detaching	Loading	Harvesting
1	1	1	2	73 ± 16[a]	108 ± 10[a]	26 ± 6	207± 22[a]
2	1	1	3	46 ± 12[bc]	100 ± 21[ab]	12 ± 3	158 ± 08[bc]
3	1	2	2	81 ± 7[ab]	79 ± 7[abc]	27 ± 12	186 ± 25[ab]
4	1	2	3	45 ± 6[bc]	83 ± 17[abc]	18 ± 11	146 ± 15[bcd]
5	2	1	2	38 ± 14[c]	89 ± 1[abc]	29 ± 6	156 ± 20[bcd]
6	2	1	3	20 ± 4[d]	74 ± 4[bc]	17 ± 1	112 ± 03[d]
7	2	2	2	33 ± 6[c]	65 ± 8[c]	27 ± 4	125 ± 10[cd]
8	2	2	3	32 ± 8[c]	61 ± 3[c]	20 ± 3	113 ± 10[d]

values – the mean value of 3 replicates ± a standard deviation; in each variable, the values of the different treatments followed by the different case letters – a significant difference according to Tukey's test ($P < 0.05$); the absence of letters – no significant effect due to the treatment according to the one-way ANOVA ($P < 0.05$)

ference was found among the 8 treatments. In any case, the homologous combinations of the factors of PM1 never surpassed those of PM2, and were inferior in 3 of the 4 cases and equal in the fourth, corresponding to the use of 2 operators and 2 vibrators. No significant interrelation between the different factors was observed.

The sum of the three events that constitute the full harvest time led to accumulating the effects observed in its different components and showed significant effects due to the three factors studied. PM1 systematically required a greater total harvest time than PM2 in all the homologous combinations of the rest of the factors, which determines an extremely significant effect ($P < 0.000$). The use of more vibrators led to a systematic and significant reduction in the time used ($P < 0.031$), due exclusively to its use during the detaching of the fruit. The number of workers was decisive in the placement of the different devices and in the filling of the boxes, which resulted in an extremely significant effect on the total harvest time as a whole ($P < 0.000$). However, the study of the independent effect of the 8 treatments showed that the treatments of PM1 with 2 vibrators and 3 operators did not show a significantly longer time than the treatments that used PM2. That is to say, this combination of factors, using MIU allowed for the more careful harvesting than all the combinations of the factors that used nets, without implying a significant loss of time.

The reason for the PM1 delay is obvious because the movement with nets by means of dragging them to the nearest tree requires less time than the folding, moving, placing and deploying of the MIU. However, the use of the conventional method involves the scuffing of the harvested fruit during its displacement, and its presence on the nets, making it inevitable that the fruit will be stepped on by the operators while they are working with the branch vibrators. Finally, the picked olives remain on the nets until the weight of the load inhibits its further displacement. Only then is the fruit loaded into the boxes. If, in order to avoid this event, the fruit is collected each time the harvesting of one single tree is finished, as is routinely done with PM1, the time required for the PM2 load and displacement

Table 2. The level of significance of the effects of the factors by the 3–way ANOVA and the 8 treatments by the 1–way ANOVA in each of the different variables of the harvest

Effect of	Placing	Detaching	Loading	Harvesting
Methods PM (1,2)	0.000	0.000	0.356	0.000
Method Shakers	0.412	0.000	0.473	0.031
Method Operators	0.000	0.245	0.002	0.000
Method × Shakers	0.911	0.613	0.611	0.945
Method × Operators	0.016	0.408	0.777	0.236
Shakers × Operators	0.593	0.245	0.397	0.136
Method × Shakers × Operators	0.134	0.944	0.954	0.366
Treatments	0.000	0.001	0.084	0.000

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would be much greater than that of PM1 and would not be acceptable economically, nor would it be representative of the usual use of this technique.

The different impacts brought on by the increase in the number of operators in both methods were due to distinct working procedures. The movement and deployment of the nets requires a minimum of 2 people to start, while the third can maintain the harness that holds the machine. On the other hand, when only 2 operators are involved in PM2, it is necessary that one or both of them, in the case of 2 vibrators, remove their harness before the operation. This act implies that the time required for the new placement of the nets in the next tree increases considerably. Even when 3 operators are active, but 2 vibrators are used, one of them must disarm the equipment before he can help transfer the nets. In PM1, one operator can start the beginning of the folding process of the MIU immediately, while the second operator is still removing his harness, hence the saving of time involved in the systematic use of three operators both with the use of 1 or 2 vibrators. Which implies a longer total harvest time than the one shown in Table 1. These facts explain the significant effect of the interrelation between the picking method and the number of workers (Table 2).

The amount collected with the MIU was 98.73%. The scarce 1.27% loss was due to a defect in the closure of the receptacle around the trunk of the tree. This observed defect can be easily corrected in the new prototype for future harvests, so the percentage of interception will be clearly above 99%.

The breakdown of the total harvesting costs clearly shows the differences among the treatments (Table 3). The main cost is presented by the operators, representing about 80% of the total cost in both picking methods. The cost of the number of shakers joined with the cost of fuel necessary for their use is the second cause of differences, varying between 6.9 and 19.1%. The cost of the MIU is about 8 times higher than the use of 6 nets, but it is only the third and the last cause of cost variation between both picking methods, falling between a range of 6.5 and 9.7% of the total cost of the PM1.

The most noteworthy result is the significantly lower cost of the conventional method (Tables 4 and 5), which does not require any design, or processing and only requires the material costs (Table 3). By making this extrapolation of costs (€·h^{-1}) with the performance of each condition (kg·h^{-1}), it is determined that the cost per ha was between 0.074 and 0.140 €·kg^{-1}, with PM2 always being significantly cheaper. According to the in-

Table 4. Cost of the collection of the different treatments constituted by the different picking methods, the number of vibrators and the number of operators.

Method	Tmt.	Shakers	Operators	€·kg^{-1}
1	1	1	2	0.136 ± 0.017^{c*}
	2	1	3	0.140 ± 0.004^{c}
	3	2	2	0.120 ± 0.016^{bc}
	4	2	3	0.128 ± 0.014^{c}
2	5	1	2	0.084 ± 0.011^{a}
	6	1	3	0.086 ± 0.002^{a}
	7	2	2	0.074 ± 0.006^{a}
	8	2	3	0.094 ± 0.008^{ab}

value – the mean value of 3 replicates ± a standard deviation; * – each variable, the values of the different treatments followed by the different case letters – a significant difference according to Tukey's test ($P < 0.05$); Tmt. – treatment

Table 3. The breakdown of the total harvesting cost, expressed in €·h^{-1}, in each combination of factors.

Harvest method	N. of shakers	N. of operators	[1]Operator cost (€·h^{-1})	[2]Boxes cost(€·h^{-1})	[3]Shaker cost (€·h^{-1})	[4]Fuel cost (€·h^{-1})	[5]Method cost (€·h^{-1})	Total harvesting cost (€·h^{-1})
PM1	1	2	16.80	0.22	1.54	0.51	2.05	21.12
	1	3	25.20	0.22	1.54	0.51	2.05	29.52
	2	2	16.80	0.22	3.08	1.02	2.05	23.17
	2	3	25.20	0.22	3.08	1.02	2.05	31.57
PM2	1	2	16.80	0.22	1.54	0.51	0.25	19.32
	1	3	25.20	0.22	1.54	0.51	0.25	27.72
	2	2	16.80	0.22	3.08	1.02	0.25	21.37
	2	3	25.20	0.22	3.08	1.02	0.25	29.77

[1]operator– 8.40 € per person; [2]boxes – 150 boxes (1.4 € per box), 10 years of useful life, used 15 days per year, 6.5 h per day; [3]shaker – 1500 € ·shaker with 10 years of useful life, used 15 days per year, 6.5 h per day; [4]fuel – 3 l per day to 1.1 € per l; [5]method – 2000 €·PM1 and 6 nets (40€ per net) during 10 years, used 15 days per year, 6.5 h per day

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depth study published by the Spanish Association of Olive Producing Townships, the total recollection cost varies according the type of olive orchard and whether irrigation is used or not (AEMO, 2012). The type of orchard defines the level of mecanization that can be used, while the use of irrigation clearly influences the total yield per ha. The study reports that for traditional olive plantations, where the recollection was performed with branch vibrators and nets, the total cost fluctuated between 0,17 €·kg^{-1} (without irrigation) and 0,15 € (with irrigation). In intensive olive groves, the use of more efficient picking machines becomes possible and the total recollection cost lowers: 0,15 €·kg^{-1}kg without irrigation and even 0,12 €·kg^{-1} with irrigation. Although a straightforward comparison is impossible, due to the specific characteristics of the used prototype, the data offers interesting references to place the obtained results in a broader perspective. Despite a large variation in the total costs, inevitable when extrapolating the data of the individual experimental units to 1 ha, the calculated results fit surprisingly well in the available data. The range of the results when picked with the MIU (0,12 and 0.14) falls within the ones obtained when using a mechanical picking machine especially when the picking is performed with the most effective combination of operators and shakers.

Table 5. Level of significance of the effects of the factors by the 3-way ANOVA and the 8 treatments by the 1-way ANOVA on the cost of collection (€·kg^{-1})

Source of variation	*P*–value
Effect of methods	0.000
Effect of shakers	0.116
Effect of operators	0.076
Effect of method × shakers	0.174
Effect of method × operators	0.595
Effect of shakers × operators	0.236
Effect of method × shakers × operators	0.509
Effect of treatments	0.000

CONCLUSIONS

In general, the use of PM1 significantly delayed the harvesting time compared to the traditional method with nets (PM2), and as a consequence, turned out to be more expensive. However, the treatment that included the combination of PM1 with 2 vibrators and 3 operators did not significantly require longer periods of time than the different combinations of treatments that used PM2. Thus, the better preservation of the quality of the olive, which implies the use of PM1, applied in the most appropriate way, should not imply a delay in the harvest nor an appreciable increase in the cost with respect to the traditional use of nets.

The fact that PM1 avoids contact with the soil and, by doing so, lowers the risk of damage of the fruit, justifies the introduction of these kind of low-cost devices, especially for small producers with a focus on optimising their olive harvest.

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