

Article

Analysis of the Almond Harvesting and Hulling Mechanization Process: A Case Study

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Abstract: The aim of this paper is the analysis of the almond harvesting system with a very high level of mechanization frequently used in Apulia for the almond harvesting and hulling process. Several tests were carried out to assess the technical aspects related to the machinery and to the mechanized harvesting system used itself, highlighting their usefulness, limits, and compatibility within the almond cultivation sector. Almonds were very easily separated from the tree, and this circumstance considerably improved the mechanical harvesting operation efficiency even if the total time was mainly affected by the time required to manoeuvre the machine and by the following manual tree beating. The mechanical pick-up from the ground was not effective, with only 30% of the dropped almond collected, which mainly was caused by both the pick-up reel of the machine being unable to approach the almonds dropped near the base of the trunk and the surface condition of the soil being unsuitably arranged for a mechanized pick-up operation. The work times concerning the hulling and screening processes, carried out at the farm, were heavily affected by several manual operations before, during, and after the executed process; nevertheless, the plant work capability varied from 170 to 200 kg/h with two operators.

Key words: almond harvest chain; hulling process; manpower employment

1. Introduction

Italy's leading regions in the production of almonds are Sicily and Apulia (Italy), with cultivated areas respectively of about 31,090 and 19,578 hectares and corresponding harvest productions of 4.69×10^7 kg and 2.20×10^7 kg. Sicily and Apulia together provide 92% of the total Italian production [1]. During last decades, Italian almond cultivation has registered a notable, progressive reduction both in terms of assigned surface area and production, despite the fact that Italy has the widest variety of almond cultivars. This dramatic crop reduction can be attributed to different reasons, such as the employment of outdated traditional orchards, competition with more profitable crops, uncertain annual yields due to adverse climatic conditions and/or pest attacks and infectious diseases, and the organization of the almond production chain and market [2]. In this regard, many of the intermediate activities involved in the almond processing (sometimes even the harvest) were taken away from the farmer and consequently have an effect on the financial gain. Furthermore there is also a considerable fragmentation because, on average, more than 40% of Italian farms involved use less than 0.20 ha in almond cultivation, and this percentage is even higher (approximately 50%) in Apulia. Nowadays, the harvesting operation, the most labour-intensive of the growth cycle, is often still carried out manually during hull dehiscence by knocking the nuts from the tree by means of long poles, collecting the almonds in nets spread on the ground. Harvest alone accounts for an average of 13–17% of the final commercial value of the almond crop [3], without considering the successive processes of hulling and drying, traditionally carried out outside the farm. The more widespread use of trunk

shakers used in olive harvesting suggested that these machines could also be used for almonds [4,5]. The employment of the trunk shaker allows a significant increase in the productivity of the individual worker [6,7]. Productivity increases further with the use of self-propelled shakers, which, in addition to the vibrating element, have a reversed-umbrella interceptor. This last solution appears to be the most interesting for the purpose of rational management of almond orchards, because the work chain is limited to two or three working units, reducing the incidence of this cost item to just 20% [8,9].

The almond harvest takes place in Italy in a different way compared to the practices in California, where the almonds farmers produce over 75% of the world's almonds. Inside Californian almond orchards, the harvest is carried out with the following operative phases: early and suitable arrangement of the soil surface (flattening, weeding, tamping), followed by the use of simple shakers to detach the almonds from the plants, side raking of the product on the soil through swathers, and picking up of the swath by means of sweepers. These sweeping practices, however, influence emissions of PM₁₀ (particulate matter $\leq 10 \mu\text{m}$ in nominal aerodynamic diameter) due to the soil material in the windrow, which may add PM emissions during almond pick-up [10,11].

Conversely, the modern Italian almond production, as all modern fruit cultivation, tends toward cultivation intensification, increasing plant density and reducing tree size. The reasons for this general evolution of fruit-growing systems should be sought primarily in reducing manpower costs due to the mechanization of farming operations, with the added value of increased workplace safety [12–17].

Taking in mind the aforementioned observations, the aim of this paper is the analysis of the almond harvesting system, with a very high level of mechanization, frequently employed in Apulia for the almond harvesting and hulling process. Several tests were carried out to assess the technical-economical aspects related to the machinery and to the mechanized harvest system used, highlighting their usefulness, limits, and compatibility within the almond cultivation sector. The analyzed harvest chain was employed by an Apulian farm in line with the standards recommended for an income almond production, both from a dimensional point of view (agricultural land devoted to almond plants of 40 ha) and an agronomic one (plants placed on irrigated flat cultivable land) with freehold machines. This study may then provide farmers with useful guidelines for machine selection in order to reduce management costs, as well as indications to optimize their use.

2. Materials and Methods

In the 36th week of 2015, experimental tests were carried out in an almond orchard ("Filippo Ceo" variety) of 40 hectares located on a farm (40°28'17.73" N, 17°38'44.64" E) in the territory of the Municipality of Oria (Brindisi Province, Southern Apulia, Italy) (Figure 1). The trees were planted with a layout of 5.0 m \times 5.0 m, giving a density of 400 trees ha⁻¹. The almond orchard was arranged on flat cultivable land with controlled growth weed and irrigation; the size of the headland access path was about 3.5 m and the main trees' structural characteristics are reported in Table 1.

Table 1. Main geometrical characteristics of the almond trees.

Trees Sizes	m
Trunk circumference	0.25–0.55
First branches height above ground level	0.60–1.00
Tree height	3.00–3.60
Canopy width	2.80–4.00
Canopy height	2.50–3.00

The harvesting chain was carried out using a self-propelled trunk shaker with a reversed-umbrella interceptor and a self-moving picker-separator, whilst the hulling process was performed through a high-capacity production huller. The self-propelled harvester by SICMA Ltd. (manufacturing company placed in Acconia di Curinga, Catanzaro Province, Italy), model "Speedy", was equipped with a 4-cylinder 93 kW diesel engine and 3-traction wheels powered by hydraulic engines. The harvester was formed by a trunk shaker (arm linked to a vibrating steerable head) and

a reversed-umbrella interceptor (5 m in diameter) (Figure 2). Furthermore, this machine was equipped with a front net to allow the largest operator's visibility and a harvest tank, able to be opened through a hydraulically operated hatch at the bottom in order to empty the contents.

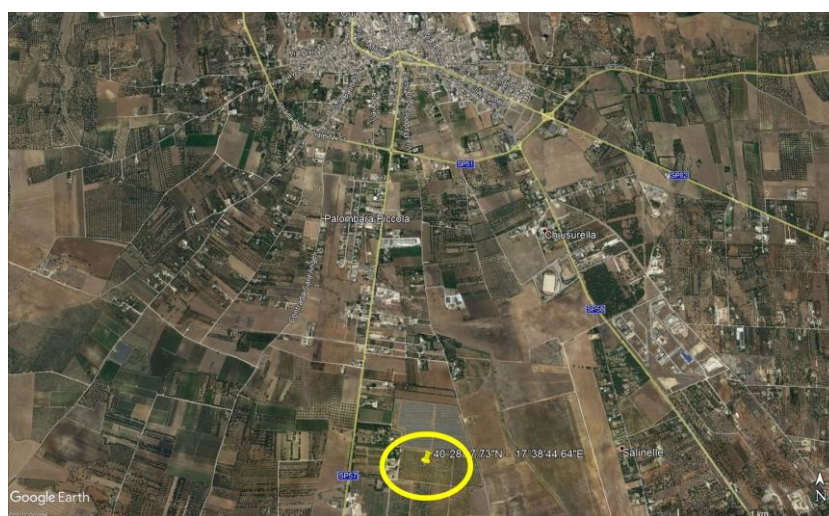


Figure 1. Map of territory of Oria, Italy, with the location of the almond orchard under test.

The self-propelled harvester was driven by a worker whilst another operator knocked the trees with a pole. A third worker was responsible for the cleaning of the product and its transport to the farm (Figure 2).

A hailstorm caused a considerable early drop of almonds just before the harvesting, and this occurrence forced us to also include a mechanized pick-up from ground operation besides the harvest carried out with the trunk shaker. This circumstance also allowed us to evaluate the performance of the mechanized pick-up operation and its feasibility in the harvesting chain.



Figure 2. Self-propelled harvester SICMA Ltd., model "Speedy"; inset shows the manual pole beating for residual product.

This ground pick-up harvesting was carried out by the articulated self-propelled harvester by De Masi Construction Ltd. (manufacturing company placed in Gioia Tauro, Italy), the model

“SHA19” picker-upper machine, equipped with a 3-cylinder diesel engine of 12.5 kW. Its 1.5-m working width front gatherer had a pick-up reel with six brushes, and a hopper with a perforated bottom to allow the expulsion of any thin impurities (Figure 3). A worker operated the picker-upper machine, while a further employee attended to the cleaning of the product and its transport to the farm.



Figure 3. Self-propelled picker-upper machine De Masi Construction Ltd., model “SHA19”.

The hulling process was performed through a crafted hulling machine made up by a horizontal cylindrical cage (length 2.87 m, diameter 0.30 m), manufactured by a mean of equally spaced steel rods, containing the hulling device, i.e., a rotating shaft equipped with stiff bodies (molded steel rods) able to separate the hull from the shell. The machine was driven by an electric motor of 1.5 kW. A worker controlled the process and took care of cleaning the product, the hopper filling, the conveyor belt activation, and periodic maintenance of the machine. A further employee took care of the quality control and the dimensional classification of the almonds (Figure 4).



Figure 4. Crafted hulling machine.

The flow chart of Figure 5 summarizes the operations chain performed during the harvesting phase; conversely, the hulling process, carried out outdoors at the farm, was organized as shown in Figure 6.

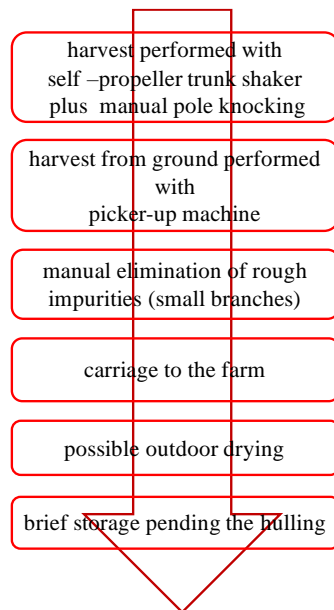


Figure 5. Almond harvesting process performed from the tree and ground.

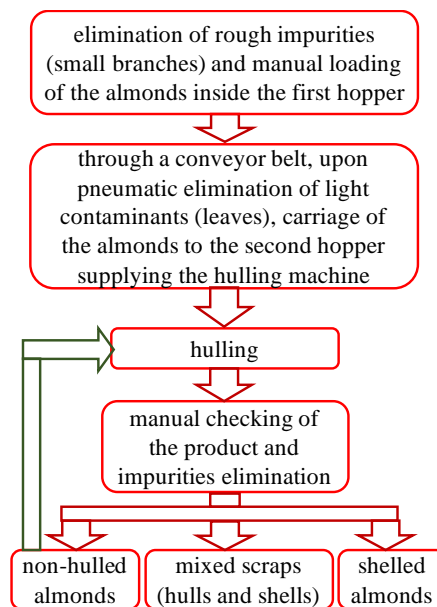


Figure 6. Flow of the almond hulling and screening processes.

3. Results and Discussion

The performance of the self-propelled harvester SIGMA “Speedy”, summarized in Table 2, confirms results already found with similar machines used for mechanized harvest in olive orchards [4,5]; altogether, the mechanized harvesting of each tree required less than 2 min with a harvesting capacity within the range 32–36 trees·h⁻¹, corresponding to more than 11 h·ha⁻¹, and the harvesting chain productivity was affected by the amount of the hanging product (9–12 kg·tree⁻¹), equal to 250–400 kg·h⁻¹.

Table 2. Almond mechanized harvesting chain and manual beating average productivity (average hanging production: 10.6 kg·tree⁻¹, corresponding to 4240 kg·ha⁻¹).

Harvesting time	s·tree ⁻¹	102
Harvesting capacity	h·ha ⁻¹	11.3
	kg·h ⁻¹	3.7
Harvesting chain and labor productivity	number of trees·h ⁻¹	35
	worker hour·ha ⁻¹	34

A more detailed analysis of the harvest times highlighted that the tree-shaking operation required only a few seconds (3–6 s), whilst the remaining time was taken up by: (i) operations such as the approach of the machine to the tree, the trunk gripping and release; (ii) the opening and closing of the reverse-umbrella interceptor; (iii) the manual beating in order to harvest almonds that did not fall from the tree; (iv) the first manual sorting operation to eliminate the largest impurities such as twigs before conveying the harvested product to the farm. Mechanized harvesting followed by manual beating allowed a detaching rate greater than 98% of the whole product on the tree. Conversely, the workers' productivity, affected by the amount of the hanging product, was on the average 0.80 worker hours (100 kg)⁻¹, i.e., 2.5 to 3.5 times that required for the manual harvest (Table 3) [2,3].

Table 3. Machines and labor productivity for the manual and mechanical almonds harvesting.

Operations	Machine-Hours/100 kg	Worker-Hours/100 kg
Manual beating and product recovery through nets	-	2.0–2.7 ¹
Mechanical harvest through shaker with interceptor and manual beating	0.27	0.80
Mechanical ground pick-up harvesting	0.37	0.75
Total	0.64	1.55
Hulling	0.60	1.2

¹ The average values reported for the production of 10 kg per hectare of almond plants are reduced to less than half in the case of productions of 2.5 to 3 kg/plant.

The articulated self-propelled harvester De Masi “SHA19” allowed for the pick-up of almonds placed on the ground, both those that dropped for natural reasons and due to the hailstorm (approximately the 14% of the total available product) and those not picked up by the umbrella interceptor (almost the 12% of the total hanging product).

The tests pertinent to the mechanized ground pick-up harvesting pointed out a high level of productivity (1.5 h·ha⁻¹) obtained by the aforementioned self-propelled harvester, even with high levels of impurities. On the other hand, the harvester had a low productivity in reference to the picked-up almonds from a single tree (only 1 kg of picked-up product per 3 kg dropped). The main reason for this poor performance is the falling of the almonds in a region very close to the tree trunk base. Those dropped almonds could not be intercepted by the umbrella due to its poor sealing around the trunk, nor by the ground harvesting machine as the ground surface was not well-flattened. Furthermore, the mechanized ground pick-up harvesting required an amount of labor (0.75 worker-hours/100 kg) that was almost the same as that necessary for the mechanized harvesting followed by the manual beating (0.80 worker-hours/100 kg) (Table 3). Therefore, these three operations all together reduced significantly the advantage of the mechanical harvesting compared to the traditional manual harvesting (1.55 vs. 2.0–2.7 worker-hours/100 kg in Table 3).

The harvest testing carried out highlighted the suitability of the mechanized process of almond harvesting from the trees, despite some burdensomeness in the ground picking-up phase if no adequate arrangement of the ground itself had been carried out and in the wrapping collar dimensional adjustment of the intercepting umbrella (Figure 7).

The work times concerning the hulling and screening processes (Figure 6), carried out at the farm, were heavily affected by several manual operations before, during, and after the executed process. Within the hulling process, these operations can be classified in chronological order as preparatory, parallel, and succeeding.

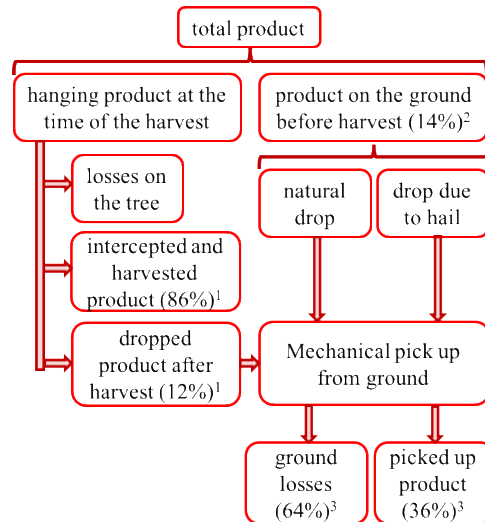


Figure 7. Average percentages referring to crop harvested from the tree, picked-up from the ground, and losses observed. (¹ referred to the whole hanging crop; ² referred to the total available crop; ³ referred to the fallen crop).

The preparatory operations were related to further impurities separation, manually for the rough ones and pneumatically for lightest ones, as well as the uneven feeding of the hopper and hulling machine; conversely, the hulling process control and the cylindrical cage cleanliness were the main parallel operations; finally, the succeeding operations included sorting the final product from impurities and re-inserting non-hulled almonds back into the hulling machine. The plant work capability varied from 170 to 200 kg/h with two operators, and the product characteristics at the input and output of working chain are reported respectively in Figures 8a,b. The hulled product features are shown in Figure 8c.

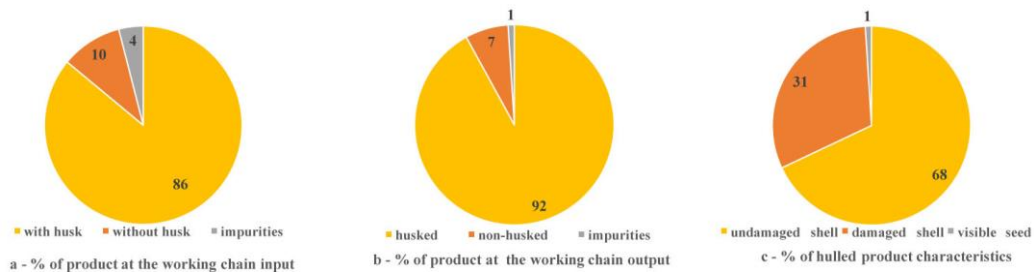


Figure 8. Average characteristics of sampled product before and after the hulling process (% values in weight).

4. Conclusions

Although limited to just one year of tests carried out within an almond orchard at the harvesting time, this research provides some useful evaluation elements related to the efficiency of the used machines and of the harvest chain under test. It has been clearly verified that, even if the almonds can be easily detached from the tree, the total harvesting time is not as low as could be expected because only the tree-shaking time is reduced, not the time necessary for the umbrella positioning and the manual tree beating. Conversely, the ground harvesting machine highlighted a poor productivity in reference to the picked-up almonds from a single tree due to the not well-flattened ground surface and the poor performance of the machine in picking up the almonds very close to the trunks.

The hulling and screening processes were executed at the farm and influenced by a lot of manual operations before, during, and after the performed process.

In agreement with the result obtained, some actions may be proposed:

- to supply guidelines to farmers for the choice of machines, which take into account their optimized employment and cost restraint;
- to study the setup of umbrella interceptors dimensionally consistent with the diameter of the trunks and the plant canopy;
- to encourage farmers to adopt the Californian almond harvesting modalities, founded on the preliminary smoothing of the ground surface and the use of simple shredders to detach the almond from the trees followed by the employment of ground harvesters.

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Conflicts of Interest: The authors declare no conflict of interest.

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