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Harvesting of *Arachis hypogaea* L. in an Italian Area: Synergy between Cultural Techniques and Mechanization

Maura Sannino [1], Alberto Assirelli [2,*], Rossella Piscopo [1], Fausto Esposito [2] and Salvatore Faugno [1]

[1] Department of Agriculture, University of Naples Federico II, Portici, 80055 Napoli, Italy; maura.sannino@unina.it (M.S.); rossella.piscopo@unina.it (R.P.); faugno@unina.it (S.F.)
[2] Consiglio per la Ricerca in Agricoltura e l'Analisi dell'Economia Agraria, Centro di Ingegneria e Trasformazioni Agroalimentari (CREA-IT), Via della Pascolare 16, Monterotondo Scalo, 00015 Rome, Italy; fausto.esposito@crea.gov.it
* Correspondence: alberto.assirelli@crea.gov.it

Abstract: The world production of peanuts is 45.9 million tons, of which China and India account for 50% of the total production. The cultivation of peanuts in Italy has had a reduction in recent decades mainly due to the high harvesting costs due to a lack of specific mechanization despite possessing favorable soil and climatic conditions. In this work, modern harvesting technologies are analyzed for adaptation to Italian areas and loss containment, and agronomic technique adaptation for mechanical harvesting. The mechanical harvesting was evaluated in two steps: plant extraction and separation pods. The results showed that lower planting density led to approximately 22% higher production and reduction in crop losses (−52%). The same trend showed that yield and harvesting efficiency were found to be 40% and 22% higher. Our research aimed to evaluate the impact of new technologies integrated by suitable agronomic management, grain losses, and the quality of the final product obtained. The lowest density also improved the healthy pod rate by 11%, from 59 to 70%. These results suggest that an integration of modern technologies and specific agronomic management improves pod retention during harvesting.

Keywords: *Arachis* quality; pod separation; plant extraction; digger; peanut harvest

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1. Introduction

Peanut (*Arachis hypogaea* L.) holds the position of the fourth most vital source of edible oil and the third most valuable source of vegetable protein worldwide [1,2]. Peanuts are annual dioecious plants, and the harvesting of peanut pods involves extracting them from the ground and pod separation and cleaning. Typically, a pod contains two to three oval-shaped seeds, each composed of two lobes [3]. This herbaceous species is primarily cultivated in Asia (China, India, Myanmar), Africa (Nigeria, Sudan), and the USA, with global production reaching 45.9 million tons [4]. Peanut cultivation, in terms of surface, spread in Italy after World War II, reaching a peak of 5600 hectares in 1961. Despite a decline in surface cultivation, consumption has increased, exceeding 600,000 tons in the European Union, with Italy accounting for 30,000 tons. In the past fifteen years, interest in this crop has gradually declined, with peanut cultivation area decreasing from 164 hectares in 2006 to 48 hectares in 2020 [5]. The main reason for the surface decreases of this crop is mainly related to difficulties with mechanized harvesting, which is the most critical phase of the entire cultivation process, requiring operational excellence achievable using new technologies to increase yield and productivity, and reduce costs [6]. Mechanized peanut harvesting involves two operational phases, a digging inverter of plants and pod separation, and is responsible for losses when not carefully managed, ranging from 3.1% to 47.1% of pod losses relative to yield [7–9].

The mechanical harvesting of peanut must be promptly carried out, and fine setting of the machine is the most important aspect for containing losses and preventing peanut damage [7]. The University of Naples Federico II (UNINA) and the Council of agricultural research and economics (CREA) have gained experience in the evaluation of emerging supply chains [10,11] and residual valorization of edible crops in terms of technologies and the efficiency of monitored construction sites in the bioenergy and fiber crop sector from which various ideas have been taken for the present experience.

The reintroduction of the peanut production chain in Italy would reduce imports from abroad and enable the market to offer a fully "Made in Italy" product, thus opening new competitive scenarios in the local, national, and international markets [12,13]. The objective of this study is to evaluate peanut cultivation in the Italian territory using specific machines for the harvesting phase and a different field management, to identify the best strategy to maximize qualitative and quantitative production and the efficiency of harvesting machines as a function of agronomic management.

2. Materials and Methods

2.1. Area of Study, Cultivar, and Machines

The experimentation required a preliminary study phase, carried out in the previous years [13,14], aimed at selecting the suitable cultivar for the pedological conditions of the area, the best setting machinery to be used for harvesting, and suitable agronomic and field management.

The study was conducted from 2021 to 2022, involving two cycles of peanut cultivation, in southern Italy (14°7′44.36″ E; latitude 41°12′6.41″ N, 89 m above sea level), on a farm characterized by a loamy soil type tending toward sandy, composed of 34.4% clay, 37.7% sand, and 27.9% silt. The total cultivated field had a study area of 1.34 hectares (204 m × 66 m).

The region has a Mediterranean climate, defined as moderately arid during the summer season, with an average annual temperature of 16.83 °C. During the experimentation, this area recorded annual precipitation of 104.4 mm and an average temperature of 22.76 °C, measured with a PCE-FWS 20 weather station (PCE Instruments, Lucca, Italy). Raspberry Pi was with a Linux-based software number WeeWX data logger connected via USB to the PCE-FWS 20 station.

The Bulgarian variety of peanuts, Lotus, was chosen for the study, characterized by an excellent vigor and prevalent commercial line in the shell. The initial soil preparation tasks, including plowing and harrowing, took place in both October and March, and the seeding was carried out in April for all two years. These operations aimed to create favorable conditions for germination [15]. To manage weeds during the crop cycle, two rounds of mechanical weeding were conducted by a spring weeder/interrow.

During the summer, the field test was irrigated using drip hoses with a diameter of 16 mm and a spacing of 20 cm, with a flow rate of 2.1 Lm h^{-1}. A total irrigation volume of 590 mm was applied for both years.

Seeding was performed with a soil temperature (10 cm depth), recorded using an RTDs Pt100 probe, of 16 °C.

A seed rate of 135 $kgha^{-1}$ was used, employing a precision pneumatic seeder, Gaspardo SP 540, with 4 rows, whose technical features are a weight of 550 kg, a row spacing of 75 cm, a 2.5-m-wide implement bar, a power requirement of 44 kW, and a working speed of 6 km h^{-1}.

The Scrape Hull method was employed to determine the optimum harvesting time. This method involves randomly collecting 100 pods developed within the study area. The ideal harvesting time occurs when, by scraping the mesocarp, 70% of the fruits are ripe. A tractor with an engine power of 89 kW (120 HP) was utilized for the harvesting process, with the respective harvesting machinery attached for the two different stages (digging and separation).

For digging, the MIAC C-200 model digger–inverter (Figure 1a) specifically designed for peanuts was employed, with its main technical features displayed in Table 1.

(a) (b)

Figure 1. (**a**) Digging inverter machine adopted. (**b**) Particulars of the threshing system adopted in separation machine.

Table 1. Main features of the inverter machine and the separation machine.

Parameters	Digger–Inverter C-200	Colombo Double Master II Harvester
Weight	860 kg	4000 kg
Height	1.65 m	4 m
Length	3.50 m	6.7 m
Total width	2.16 m	-
Working width	1.5 m	1.5 m
Total length	-	2.5 m
Power required	-	from 58 to 81 kW

After the passage of the digger, the plants were left to dry in ridges (1.50 m × 204 m) on the ground until reaching a suitable moisture content for the second harvesting phase [8–16]. Moisture during the digging phase and the separation phase was measured using the Moisture Meter (Smart Sensor AR991 by Shenzhen Handsome Technology Co., Ltd., Shenzhen, China). The second harvesting phase, which involves separating the pods, was carried out using the MIAC Colombo Double Master II Harvester machine (Figure 1b), specifically designed for this crop. The choice of this type of separator machine was based on study [15], which states that axial combine harvesters have less losses during the separation phase compared to tangential ones. Table 1 shows the technical features of the operating machine.

2.2. Experimental Setup, Sampling, and Analysis

Following a preliminary study on the methods of peanut cultivation in the European and American peanut field, two densities close to the average values found were chosen to evaluate any influences on mechanized harvesting and quality of the peanuts obtained. The experimental design included the division of study area into 2 parcels, each measuring 0.48 ha (204 m × 22 m). Each parcel was further divided into two sub-areas of 0.24 ha (204 m × 11 m), each with a different treatment. The treatments consisted of two crop densities: 13 pt m^{-2} (D_1) with a planting distance of 10 cm on the row and 75 cm between rows, and 17 pt m^{-2} (D_2) with a planting distance of 7.5 cm on the row and 75 cm between rows.

The estimated yield, the water content in the pods, total losses during the digging phase, total losses during the separation phase, net yield, speed, effective field capacity and hourly harvest efficiency, harvest quality, and effective fuel consumption were assessed.

The estimated yield (EY) was assessed before the digging phase by manually harvesting all plants in three plot replicates for each sub-area. The plot replicates, measuring 1.5 m^2 (1.5 m × 1 m), were randomly selected, avoiding boundary areas. The harvested plants were then stored in labeled paper bags and sent to the Laboratory of Mechanical

Engineering at the Department of Agriculture of the University of Naples Federico II. In the laboratory, the pods were separated from the plant biomass, cleaned to remove mesocarp impurities, and weighed on a digital scale with a precision of 0.001 g (ALC-107 T535 PK130R, Winchester, VA, USA). The moisture content was determined according to [17]. After drying, the pods were weighed again to determine the estimated yield, with an 8% correction for humidity, which is the moisture content used for peanut storage. The estimated yield was converted to t ha^{-1} (hectares) according to [18].

Excavation losses were divided into visible losses (DVL), invisible losses (DIL), and total digging losses (DTL), which are the sum of visible and invisible losses, as suggested in [19]. After the passage of the digger–inverter, the row was manually moved, and three plot replicates, measuring 1.5 m^2 (1.5 m $\times$ 1 m), were selected for each experimental treatment. The pods remaining on the surface were classified as visible losses (DVL), while the pods within the top 15 cm of soil were classified as invisible losses (DIL).

To evaluate the losses (SL) during the separation phase, three plot replicates, measuring 1.5 m^2 (1.5 m $\times$ 1 m), were sampled in each sub-area after the passage of the Colombo Double Master II Harvester machine.

The DVL, DIL, and SL were manually collected in paper bags, labeled, and sent to the laboratory, where the same procedure used for estimated yield estimation was repeated for both the digging losses and separation losses. The harvest total losses (HL) were calculated as the sum of DTL and SL and expressed in kg ha^{-1}.

The yield (Y) was calculated by considering the estimated yield without total excavation losses (DTL) plus separation losses (SL) and expressed in t ha^{-1}.

The harvesting efficiency was calculated as the percentage ratio of yield (Y) to estimated yield (EY). The harvest phases were analyzed following the CIOSTA methodology and the recommendations of the Italian Society of Agricultural Engineering (AIIA) 3° R1. Regarding the working times, including the field setting to the digger–inverter knives' width and unexpected events such as blockage removal, and unloading time for the separation machine, all data were recorded.

The effective speed of the tractor with the two machines was measured using a radar (RVS II) attached to an original datalogger of the tractor (CR23X).

The effective field capacity (EFC) is a function of field speed, machine working width, field efficiency, and unit yield of the field. Area capacity is expressed and was obtained based on the working width of the two operating machines combined with the tractor and the travel speed and field efficiency, according to [20].

The formula used, according to [20], is

$$C_a = \frac{swE_f}{10} \tag{1}$$

where:

C_a = area capacity (ha h^{-1})
s = field speed (km h^{-1})
w = implement working width (m)
E_f = field efficiency, decimal

To assess the entire harvesting cycle, 5 samples of pods were collected directly at the exit of the conveyor belt of the separating machine for each sub-plot [15], for a total of 30 samples weighing 1 kg each. The samples were collected using a 1000 mL container, bagged, and labeled. In the laboratory, they were sorted into whole pods (EP), damaged pods (OP), seedless pods (SP), vegetable impurities (VI), and mineral impurities (MI), and then weighed, with the values expressed in grams.

2.3. Data Analysis

A statistical analysis was performed using R Studio software (version 4.2.2). Prior to the analysis, the normality and homogeneity of variance of the data were checked using the Shapiro–Wilks test and Bartlett test. After confirming the validity of the data, the differences in the effect of the two densities on the mechanical variables analyzed were analyzed using a 1-way ANOVA test, considering each plot replica as the experimental unit. A probability of $p \leq 0.05$ was considered significant.

3. Results

The harvesting was carried out for the two years in the second half of September, when the Scrape Hull method found 70% ripe fruits.

For the evaluation of pod maturity, the Scrape Hull maturity assessment method adopted revealed no significant differences in maturity between the two planting densities. To evaluate the effect of the two densities on the mechanical variables, a one-way ANOVA test was performed. Density had a significant effect on the dependent variables examined in the study. Table 2 shows the results of the average values of the digging and separation losses.

Table 2. Digging and Separation losses for each density (D_1 and D_2) during the harvest tests.

Variables	D_1	D_2	*p*-Value
DVL, g m^{-2}	6.8 ± 1.9	13.1 ± 1.9	*
DIL, g m^{-2}	2.65 ± 1.0	27.8 ± 1.1	*
DTL, g m^{-2}	9.45 ± 4.5	40.9 ± 4.2	*
SL, g m^{-2}	5.3 ± 1.4	15.7 ± 1.6	*

DVL = excavation visible losses, DIL = excavation invisible losses, DTL = total digging losses, SL = separation losses. * $p < 0.05$.

The average values for total losses during the digging phase (DTL), expressed in g m^{-2}, were the result of the sum of visible losses (DVL) and invisible losses (DIL). DVL represents the pods detached from the plant and present on the soil surface, while DIL includes the pods retained within the top 15 cm of soil. From the statistical analysis, it emerged that DVL and DIL were significantly higher ($p < 0.05$), 50% and 90%, respectively, in sub-plots with higher density (D_2), resulting in a 78% increase in DTL. Density D_2 negatively influenced the average total losses, primarily due to DIL, which accounted for 70% of DTL.

After the digging phase, the plants remained on the ground for 4 days until the pods reached an average moisture content of 18.8%, according to [16], which states that the ideal moisture range for the start of the separation phase is between 18 and 24%. The separation phase was carried out using the Colombo Double Master II Harvester. At the end of this phase, the remaining pods on the ground and not intercepted by the separating machine were manually collected within the plot replica of the sub-plots, and these losses (SL) were expressed in g m^{-2}. The statistical analysis showed a reduction in SL in sub-plots with lower density (D_1) by approximately 64%.

The results of the other variables examined in this study, such as estimated production, total harvest losses, yield, and harvest efficiency, are shown in Table 3 for the average value of two years.

Table 3. Harvest total losses and harvest efficiency for each density (D_1 and D_2) during the experimental study.

Variables	D_1	D_2	*p*-Value
EY, t ha^{-1}	2.74 ± 3.6	2.11 ± 3.0	*
HL, kg ha^{-1}	214 ± 4.52	566 ± 4.94	*
Y, t ha^{-1}	2.43 ± 6.58	1.65 ± 6.66	*
E, %	0.91 ± 0.03	0.73 ± 0.04	*

EY = estimated yield, HL = harvest total losses, Y = yield, E = harvester efficiency. * $p < 0.05$.

Regarding the estimated yield, the results showed a higher production level, approximately 22% more, in sub-plots with a lower planting density (D_1).

The total harvest losses (HL), calculated as the sum of DTL and SL, were expressed in kg ha^{-1}. The HL were significantly lower (52%) when the machines worked in the sub-plots of density D_1). The total losses (HL) during the entire harvest, compared to the reliable production, were 11% for D_1 and 29% for D_2.

The yield (Y) calculated considering the estimated yield net of total excavation losses (DTL) added to separation losses (SL), and the harvesting efficiency calculated as the percentage ratio of yield (Y) to estimated yield (EY), were significantly higher in the sub-plots with lower plant densities (D_1). In fact, the yield and harvesting efficiency obtained in the D_1 sub-plots were 40% and 22% higher, respectively, compared to the values of the D_2 sub-plots.

Table 4 shows the main performances of the two machines adopted for digging and separation phases for two densities evaluated. The emerged original aspects concern the difference from the machine trailed and mounted with improvement for the last type. Similar effective field capacity for different machines with or without the unloading phase necessary completed the working harvest of peanuts. The yield from all production is unloaded in a plastic big-bag specific for sowing seed production for all year tests.

The effect of planting density on harvesting efficiency in terms of the quality of the obtained product presents a significant difference also for material capacity, which exceeds 0.5 t h^{-1}.

In terms of seed quality from our results, reported in Table 5, significant differences ($p < 0.05$) were found in the average percentage of healthy pods between the two considered planting densities. In particular, the lower planting density (D_1) resulted in an average percentage of healthy pods of 70%, while the higher planting density (D_2) recorded an average percentage of 59%.

These results indicate that for two years, a lower planting density favors the preservation of pods during the harvesting operation. We observed a 14% increase in the quantity of intact pods (EP) with the D_1 planting density, compared to the D_2 density. Additionally, we highlighted a 19% reduction in damaged pods (OP), a significant 45% reduction in empty pods (SP), and a 74% reduction in ground residues (MI) with the D_1 planting density, compared to the D_2 density.

Table 4. Time and performance characteristics for each density (D_1 and D_2).

Parameter	D_1				D_2			
	Digger–Inverter		Separation		Digger–Inverter		Separation	
	Value	%	Value	%	Value	%	Value	%
Effective time (TE), s	2754.0	81.48	2295.0	59.83	2898.9	79.80	2343.8	60.97
Accessory time (TA), s	625.91	18.52	1540.91	40.17	733.64	20.20	1500.45	39.03
Turning time (TAV), s	295.91	8.75	370.91	9.67	313.64	8.63	380.45	9.90
Supply and unloading time (TAS), s	0	0.00	720	18.77	0	0.00	560	14.57
Field setting time (TAC), s	330	9.76	450	11.73	420	11.56	560	14.57
Total, s	3379.9	100	3835.9	100	3632.6	100	3844.3	100
Effective speed, km h^{-1}	4		4.8		3.8		4.7	
Operating speed, km h^{-1}	3.26		2.87		3.03		2.87	
Effective field capacity, ha h^{-1}	0.49		0.43		0.45		0.43	
Material capacity, t h^{-1}	2.57				1.98			

Table 5. Quality of mechanical harvest (referred 1000 g of sample), for each density (D1 and D2).

	D_1	D_2	*p*-Value
OP	154.0 ± 37.2	189.5 ± 39.2	*
SP	61.6 ± 27.8	119.3 ± 28.2	*
VI	12.1 ± 5.6	13.9 ± 5.3	ns
MI	4.3 ± 3.5	28.79 ± 4.0	*
EP	760.7 ± 44.0	655.7 ± 46.7	*

OP: damaged pods; SP: seedless pods; VI: vegetable impurities; MI: mineral impurities; EP: whole pods. * $p < 0.05$; ns = no significance in the averages of the variables analyzed ($p > 0.05$).

4. Discussion

The reintegration of peanut cultivation in Italy faces an obstacle associated with the complexities of mechanized harvesting. The harvesting phase is crucial in the continuum of agricultural production and requires a good synergy between agronomic practices and machines to improve operational efficiency, reduce production costs, and increase product yield [6]. Predominantly, the excavation phase is marked by substantial losses (ranging from 3.1% to 47.1%), primarily resulting from suboptimal management practices [7,8]. In the extraction and turning of the plants, which is the initial harvesting phase involving swathing, the solidity of the peduncle connecting the plant to the fruit is crucial. Any damage or failure to it results in the loss of the product onto the ground. The conducted measurements revealed whole pods detached and on the ground. Addressing this issue will be the focus of future experimentation to identify varieties or cultivation techniques capable of minimizing this criticality. In this context, the machine setting did not reveal solutions with the same functional principle that was adopted. The next phase involves the separation of the pods, preliminary cleaning, and their subsequent storage. The separation of the peanuts from the plants, which constitutes the second mechanical harvesting phase, requires conditions opposite to those of plant extraction (first phase). In this case, the resistance of the connecting peduncle is responsible for the lack of separation, resulting in the loss of product remaining attached to the plant. The reasons why even the most modern technologies cannot accomplish the collection in a single step precisely fall into these aspects that emerged during the experiments. The peduncle should be elastic during the plant extraction phase when wet and not elastic but easy to break after losing moisture (critical aspects highlighted for mechanized harvesting).

As indicated by references [8,16], the Scrape Hull method was applied, and the commencement of harvesting operations coincided with the moment when 70% of the fruits in the field had reached maturity, while the average moisture content of the pods stood at 40%. The timing of the harvest initiation is of paramount importance, as any delay in this process can lead to increased product losses during the harvesting phase. This delay is primarily attributed to the excessive desiccation of the plants, which results in a weakened attachment between the peanuts and the underground portion of the plant, rendering them more susceptible to detachment during the excavation phase and breakage during the separation phase. Consequently, this leads to a reduction in operational efficiency at the harvesting site and a decrease in the quality of the harvested product [7].

The harvesting phase is critical because it represents a key moment in agricultural production. We evaluated losses during mechanized harvesting by analyzing losses during the digging phase (DTL) with the MIAC C-200 model digger–inverter and losses during the separation phase (SL) with the Colombo Double Master II Harvester machine.

Losses during the digging phase were expressed through two types of losses: visible losses (DVL) and invisible losses (DIL). Visible losses refer to pods detached from the plant and lying on the soil surface, while invisible losses include pods retained within the top 15 cm of soil.

The results, as shown in Table 2, highlight that DVL and DIL increased significantly (13.1 ± 1.9 g m^{-2} and 27.8 ± 1.1 g m^{-2}) in sub-plots with higher planting density (D_2) compared to sub-plots with lower planting density (D_1), where DVL and DIL were

6.8 ± 1.9 g m^{-2} and 2.65 ± 1.0 gm^{-2}, respectively. The increase in these losses led to a considerable overall increase (+78%) in total losses (DTL) in sub-plots with higher planting density compared to those with lower planting density. Notably, the component that had the most significant impact on total losses in higher planting density sub-plots was invisible losses (DIL), which accounted for as much as 70% of the total losses. On the contrary, we observed that lower planting density (D_1) promoted a significant reduction in invisible losses (DIL) and, consequently, total losses (DTL). The results of our study confirm and expand upon what was previously reported by other researchers [21] regarding the importance of planting density in agricultural practices. In particular, it was observed that lower planting density can result in significant benefits in terms of yield and peanut plant development. Lower planting density encourages full pod maturation and enhances peduncle strength, thereby reducing the risk of premature detachment during mechanized digging, resulting in reduced losses.

The second phase of harvesting commenced when the pods reached an average moisture content of 18.8%, in accordance with the recommendations of the author of [16], who suggests that the ideal moisture range for commencing the separation phase falls between 18 and 24%. Losses during the separation phase (SL), which are defined as pods left on the ground and not intercepted by the separating machine, were significantly higher in sub-plots with higher planting density (D_2) compared to sub-plots with lower planting density (D_1), specifically 15.7 ± 1.6 g m^{-2} versus 5.3 ± 1.4 g m^{-2}. The SL results obtained in this study are in line with the range (6.38–18.51 g m^{-2}) of separation losses reported in another study [15]. Furthermore, the SL (separation losses) were significantly lower than the DTL (digging losses) for both densities, with a reduction of 42% for density D_1 and 55% for density D_2. This result is consistent with other studies [8,22], which assert that most losses during the mechanized harvesting phase of peanuts occur during the digging operation.

Table 3 presents the results of effective yield (EY), total losses from mechanized harvesting (HL), net yield (Y), and mechanized harvesting efficiency (E).

Concerning the estimated average production (EY), the results demonstrated a higher production level, approximately 22%, in sub-plots with lower planting density (D_1). This increase could be attributed to the greater distance between plants, allowing for enhanced pod development and reduced competition for space. This result aligns with another study [23] where a significant increase in peanut pod yield was observed with a density of approximately 12 pt m^{-2}. Determining the optimal plant density is a crucial agronomic goal to maximize yield because maximum production can only be achieved if the canopy intercepts as much sunlight as possible [24], and if the physiological activity of the roots is not compromised by competition for water, nutrients, and space [21]. Planting density plays a fundamental role in peanut production, and the choice of appropriate density could be a key factor in ensuring optimal yield.

Total losses from mechanized harvesting (HL), which result from the sum of total losses during the digging phase (DTL) and the separation phase (SL), were significantly lower (52%) when machines worked in sub-plots with density D_1. This result reinforces what is stated by the authors of [25], who argue that planting density is a fundamental agronomic factor for good mechanized peanut harvesting efficiency in terms of product losses. The HL throughout the entire harvest, relative to the estimated production, was 11% for D_1 and 29% for D_2. The HL values obtained in this study are encouraging, especially when compared to those obtained in other studies where only digging losses ranged from 3.1% to 47% [8,19].

The yield (Y), calculated by considering the estimated yield net of total losses throughout the entire harvesting phase (HL), and the harvesting efficiency calculated as the percentage ratio between yield (Y) and estimated yield (EY), were significantly higher in sub-plots with lower planting density (D_1). In fact, the yield and harvesting efficiency obtained in D_1 sub-plots were 40% and 22% higher, respectively, compared to the values of D_2 sub-plots. This result reaffirms the importance of choosing an appropriate planting density to ensure greater mechanized harvesting efficiency. It is interesting to note that the average harvesting efficiency observed in D_2 sub-plots in this study is in line with the range of values reported in the reference study [26]. This suggests that this study aligns with existing evidence in the field of agricultural harvesting. On the other hand, the average harvesting efficiency in sub-plots with lower density (D_1) is over 20% higher than what was reported in study [26]. This result could be attributed to environmental aspects, such as soil conditions or specific cultivation techniques, and the peanut variety used in this area, which may have contributed to the observed increase in mechanized harvesting efficiency.

Taking the two sowing densities as reference (Table 4), no substantial differences were shown in the performance of the two machines used for harvesting in the phases that follow, the extraction and digging phase and separating and unloading pods. The study of the times shows rather typical values of machines operating continuously without any other phases. Over 80% of effective time drops to around 60% of the separating phase where an unloading phase is foreseen and therefore interruption of the harvesting cycle, approach to trailer and unloading of the pods in a plastic bag for storage. In this way, the accessory time is increased to 20 and 14% for unloading phases. The effective working speeds in the field for the digging machine, however, also remain very similar between the two densities with a difference of just 0.2 km h^{-1} between D_2 and D_1, while for the separation phase, the difference is just 0.1 km h^{-1}, which disappears when moving to the operating speed, where they become equal.

Regarding the mechanized harvesting efficiency as a measure of the product's quality, the results are reported in Table 5. Lower plant density, as indicated by our results, appears to facilitate the separator's operation. These findings corroborate a study conducted by previous researchers [27], which posited that an increased volume of material along the separator's cylinder axis can elevate pod damage percentages and yield greater losses. Consequently, our research serves to fortify the prevailing evidence underscoring the pivotal role of planting density in optimizing harvesting efficiency and product quality. It can be specified that before these experiments, there was no commercial peanut production but primarily for self-consumption or the local market. For such a purpose, harvesting was carried out using local prototypes of rudimentary excavators and separation machines or manually with extraction plants and pod separation. As this represents the initial experience in the use of specific peanut harvest machines not tailored to the Italian area, the test aimed solely to identify whether and to what extent relationships existed between sowing density and the mechanical harvester. Once this aspect is highlighted at the most favorable density, it will be further explored in new experiments, including the evaluation of pod detachment forces from the plant.

5. Conclusions

The experience allowed us to evaluate the introduction of modern harvesting technologies in peanut cultivation in an Italian area. The agronomic management and sowing density below 15 plants per square meter has improved the yield of the crop, the containment of losses, and the quality of the product obtained especially in terms of an intact seed with an increase of 11% compared to the greater density of sowing. The mechanical harvesting both in the excavation and turning phase and in the separation pod phase did not highlight any critical issue while maintaining almost the same machine performance in both densities tested. Leak control remains an important aspect to focus on for the new tests necessary to increase the yield and quality of the product obtained and meet the growing needs of the market. Further studies will be carried out to evaluate the other crop biomass and evaluate other byproducts such as peanut husks as possible reuse with a view of actual circular economy concepts and greater sustainability of the crop.

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