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Harvesting of *Arachis hypogaea L.* in Italian Area: Synergy Be-Tween Cultural Techniques and Mechanization

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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 lack of specific mechanization despite having favorable soil and climatic conditions. In this work, in the Campania region, the performance of modern harvesting technologies developed in other areas is analyzed in terms of adaptation to Italian areas and loss containment, also adapting agronomic techniques and evaluating different production lines in terms of planting density and stages of mechanical harvesting, plants extraction and separation pods were evaluated. The results showed that lower planting density led to approximately 22% higher production. Total crop losses were significantly lower (-52%) at lower density. Yield and harvesting efficiency were found to be 40% and 22% higher respectively with lower density. Our research aimed to evaluate the impact of foreign technologies integrated by suitable agronomic management as a planting density on harvest efficiency, grain losses and the quality of the final product obtained. The lowest density resulted in a 70% healthy pod rate, while the highest density resulted in a 59% rate. These results suggest that a integration from modern techonolgies and mirate agronomic management improves pod retention during harvesting, with a 14% increase in intact pods (EP).

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1. Introduction

Peanut (Arachis hypogaea L.), also recognized as groundnut, 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 self-pollinating plants, and the harvesting of peanut pods involves extracting them from the ground. Typically, a pod contains 2 to 3 oval-shaped seeds, each composed of 2 lobes [3]. This herbaceous species is primarily cultivated in Asia (China, India, Myanmar), Africa (Nigeria, Sudan) [4], and the USA, with global production reaching 45.9 million tons [4]. Peanut cultivation spread in Italy after World War II, reaching a peak of 5,600 hectares in 1961. However, while cultivation has decreased, consumption has increased, surpassing 600,000 tons in the European Union (30,000 in Italy), all of which are imported, mainly from the USA and Argentina. 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 abandonment 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 production volume, productivity, and reduce production costs [6]. Mechanized peanut harvesting involves two operational phases: digging inverter of plants and pod separation. During the digging phase, the roots are cut, and the plants are extracted and turned over, left in the field for

3 to 5 days to allow the pods to significantly reduce moisture through direct exposure to sunlight. Most losses during peanut harvesting occur during the digging operation and can reach high levels when not carefully managed, ranging from 3.1% to 47.1% of pod losses relative to yield [7–9]. The second operational phase involves separating the pods from the plant, performing pre-cleaning, and storing the product in a tank [10].

Operations related to the second phase of harvesting must be promptly carried out once the correct moisture level is achieved. Any delay can lead to increased product losses due to excessive drying of the plants, leading to weakened peduncles connecting the peanuts to the plant, and potential breakage. As a result, the machine may face difficulties in intercepting the pods [8]. UNINA and CREA have gained experience in the evaluation of emerging supply chains [11,12] and residual valorization of edible crops in terms of technologies and the efficiency of monitored construction sites in the bioenergy and fiber crops sector from which various ideas have been taken for the present experience [13]. Currently, the Italian peanut industry is limited to processing, packaging, and commercialization.

The reintroduction of the entire 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 [14]. The objective of this study is to evaluate peanut cultivation in Italian territory using specific machines for the harvesting phase and different sowing densities, to identify the best strategy to maximize qualitative and quantitative production and the efficiency of harvesting machines and evaluate other biproducts as an almound husks [15].

2. Materials and Methods

2.1. Area Study, Cultivar and Machines

The experimentation required a preliminary study phase, carried out in the previous years [14,16], aimed at selecting the cultivar that best suited the pedological conditions of the area, the machinery to be used for harvesting, and suitable cultural strategies.

The study was conducted from 2020 to 2022 in Southern Italy (longitude 14° 7′44.36″E; latitude 41°12′6.41″N, altitude 89 m a.s.l.), on a farm characterized by a loamy soil type tending towards sandy, composed of 34.4% clay, 37.7% sand, and 27.9% silt. The total cultivated field had an area of 1.34 hectares (204 m x 66 m) and the experimental are involved 0.48 hectars for two seed density.

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, Italy). Raspberry Pi with a Linux based software data logger connected via USB to PCE-FWS 20 meteo.

The Bulgarian variety of peanuts, Lotus, was chosen for the study, characterized by excellent vigor and prevalent commercial line in shell. Initial soil preparation operations, such as plowing (October 2021), harrowing (March 2022), before sowing (April 2022), were carried out to provide the best conditions for germination [17]. Two passes with a mechanical weeder were performed during the crop cycle for weed control.

During the summer season, the entire study area was irrigated using drip hoses with a diameter of 16 mm and a spacing of 20 cm, with a flow rate of 2.1 Lmh^{-1}. A total irrigation volume of 590 mm was applied.

Seeding was done on April 28, 2022, with a soil temperature (10 cm depth) recorded using an RTDs Pt100 probe, of approximately 16 °C.

A seed rate of 135 $kgha^{-1}$ was used, employing a precision pneumatic seeder Gaspardo SP 540 with 4 rows, whose technical specifications are shown in Table 1.

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Table 1. Technical characteristics of the Gaspardo SP 540 4-row seeder.

Parameters	Values
Weight	550 Kg
Row distance	75 cm
Toolbar width	2.5 m
Power required	44 kW
Feed rate	6 Kmh^{-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 [18]. A tractor with a 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 specifically designed for peanuts was employed, with its technical specifications displayed in Figure 1 and Table 2.

Figure 1. Digging inverter machine adopted.

Table 2. Technical characteristics of the Digger-inverter C-200.

Features	Digger-inverter C-200
Weight	860 kg
Height	1.65 m
Length	3.50 m
Total width	2.16 m

After the passage of the digger, the plants were left to dry in ridges (1.50 m x 204 m) on the ground until reaching a suitable moisture content for the second harvesting phase [7,19]. Moisture during the digging phase and the separation phase was measured using the Moisture Meter (Smart Sensor AR991). The second harvesting phase, which involves separating the pods, was carried out using the MIAC Colombo Double Master II Harvester machine, specifically designed for this crop. The choice of this type of separator machine was based on a study by [17], which states that axial combine harvesters have less losses during the separation phase compared to tangential ones. Table 3 shows the technical characteristics of the operating machine.

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Table 3. Technical characteristics of the separation machine.

Features	Colombo Double Master II Harvester
Weight	4000 kg
Height	4 m
Length	6.7 m
Total length	2.5 m
Power required	da 80 CV a 110 CV

2.2. Data Analysis

The experimental design involved dividing the study area into 2 parcels, each measuring 0.48 ha (204 m x 22 m). Each parcel was further divided into two sub-areas of 0.24 ha (204 m x 11 m), each with a different treatment. The treatments consisted of two crop densities: 13 ptm^{-2} (D_1) with a planting distance of 10 cm on the row and 75 cm between rows, and 17 ptm^{-2} (D_2) with a planting distance of 7.5 cm on the row and 75 cm between rows.

The study evaluated the estimated yield, variable 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, quality, and effective fuel consumption.

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 x 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 0.001g (ALC-110.4). The moisture content was determined according to the EN1477-2:2010 standard. 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 qha^{-1} (hectares) according to Martins and Lago (2008).

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 by [21]. After the passage of the digger-inverter, the row was manually moved, and three plot replicates, measuring 1.5 m^2 (1.5 m x 1 m), were selected for each experimental treatment. The pods remaining on the surface were classified as visible losses, while the pods within the top 15 cm of soil were classified as invisible losses.

To evaluate the losses (SL) during the separation phase, three plot replicates, measuring 1.5 m^2 (1.5 m x 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 q ha^{-1}.

The yield (Y) was calculated by considering the estimated yield without total excavation losses (DTL) plus separation losses (SL) and expressed in q 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. The working times, including field setting to the digger-inverter knives' width and unexpected events such as blockage removal, and unloading time for 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 a original datalogger of the tractor (CR23X).

The effective working capacity (EFC) was obtained based on the working width of the two operating machines combined with the tractor and the travel speed, according to [7].

The formula used is:

$$EFC = WW*s* 0.36 \quad (1)$$

Where:
EFC = effective field capacity (ha h^{-1})
WW = working width of the machine (m)
s = travel speed (m s^{-1})
0.36 = unit correction factor
To assess the entire harvesting cycle, not only in quantitative terms but also in qualitative terms, 5 samples of pods were collected directly at the exit of the conveyor belt of the separating machine for each sub-plot [17], 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), mineral impurities (MI), and then weighed, with the values expressed in grams.

2.3. Statistical Analysis

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 (D_1 or D_2) test, considering each plot-replica as the experimental unit. A probability of $P \leq 0.05$ was considered significant.

3. Results e discussion

The harvesting was carried out in the second decade of September 2022 when the Scrape Hull method found 70% ripe fruits, in accordance with [18], and the average moisture content of the pods was 40%, according to [19].

To evaluate the effect of the two densities on the mechanical variables, a 1-way ANOVA test was performed. Density had a significant effect on the dependent variables examined in the study. Table 4 shows the results of the average values of the digging and separation losses.

Table 4. Digging and Separation losses during the experimental study.

Variables	D1	D2
DVL, gm^{-2}	6.8 ± 1.9a	13.1 ± 1.9b
DIL, gm^{-2}	2.65 ± 1.0a	27.8 ± 1.1b
DTL, gm^{-2}	9.45 ± 4.5a	40.9 ± 4.2b
SL, gm^{-2}	5.3 ± 1.4a	15.7 ± 1.6b

DVL= excavation visible losses, DIL= excavation invisible losses, DTL= total digging losses, SL= separation losses. [a–b]Mean values in the same line with different superscripts differ ($P < 0.05$).

The average values for total losses during the digging phase (DTL), expressed in gm^{-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, 50% and 90% respectively, in sub-plots with higher density (D2: 17 ptm^{-2}), resulting in a 78% increase in DTL. Density D2 negatively influenced the average total losses, primarily due to DIL, which accounted for 70% of DTL. The pods may not have been intercepted by the machine due to their smaller size and reduced peduncle development, resulting in detachment during the digging phase. In contrast, the results show that a lower density (D1) promotes a reduction in DIL and consequently DTL. This could be attributed to the plants' ability to fully exploit their productive potential by

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improving the distribution and speed of nutrient transfer to the pods during formation, thereby promoting pod fullness and peduncle strength during digging, as indicated in the study by [22]. This result confirms what has been stated by [22], emphasizing the importance of carefully considering planting density in agricultural practices to optimize production and harvesting phase [23].

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 [19], which states that the ideal moisture range for the start of the separation phase is between 18-24%. The separation phase was carried out using the Colombo Double Master II Harvester (Figure 2). 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 gm^{-2}. The statistical analysis showed a reduction in SL in sub-plots with lower density (D1) by approximately 64%. The SL results obtained in this study are in line with the range (6.38 - 18.51 gm^{-2}) of separation losses obtained in another study [17]. The SL (separation losses) were significantly lower ($P < 0.05$) than the DTL (digging losses) for both densities, with a reduction of 42% for density D1 and 55% for density D2. This result is in line with other studies [7,24], which state that most losses during peanut harvesting occur during the digging operation.

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 5.

Figure 2. Particular of the threshing system adopted in separation machine.

Table 5. Harvest total losses and Harvest Efficiency during the experimental study.

Variables	D_1	D_2
EY, tha^{-1}	2.74 ± 3.6^a	2.11 ± 3.0^b
HL, $kgha^{-1}$	214 ± 4.52^a	566 ± 4.94^b
Y, tha^{-1}	2.43 ± 6.58^a	1.65 ± 6.66^b
E	0.91 ± 0.03^a	0.73 ± 0.04^b

EY= estimated yield, HL = harvest total losses, Y= yield, E = Harvester Efficiency. $^{a-b}$Mean values in the same line with different superscripts differ ($P < 0.05$).

Regarding the estimated average production, the results showed a higher production level, approximately 22% more, in sub-plots with a lower planting density (D1: 13 ptm^{-2}). This could be due to the greater distance between the plants, which allowed for greater pod development and reduced competition for space. This result is in line with another study [25] where a significant increase in pod yield was observed with a density of approximately 12 ptm^{-2}. Determining the optimal plant density is an essential agronomic objective for maximizing yield, as the maximum production can only be achieved if the canopy intercepts as much sunlight as possible [26].

The total harvest losses (HL), calculated as the sum of DTL and SL, were expressed in kgha^{-1}. The HL were significantly lower (-52%) when the machines worked in the sub-plots of density D1 (13ptm^{-2}). This result highlights what has been stated by [27], who claim that planting density is a fundamental agronomic factor for successful harvesting.

The total losses (HL) during the entire harvest, compared to the reliable production, were 11% for D1 and 29% for D2. 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% [7,28].

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 (D1). In fact, the yield and harvesting efficiency obtained in the D1 sub-plots were 40% and 22% higher, respectively, compared to the values of the D2 sub-plots. This could be due to better aeration and more space between plants, allowing for more efficient harvesting. Interestingly, the average harvesting efficiency observed in the D2 sub-plots of this study is in line with the range of values reported in the reference study [29]. This suggests that this study aligns with existing evidence in the field of agricultural harvesting. On the other hand, the average harvesting efficiency in the sub-plots with lower density (D1) is more than 20% higher than what was reported in the study [29]. This result could be attributed to specific factors in the study environment, such as soil conditions or specific cultivation techniques, which may have contributed to the observed increase in harvesting efficiency.

The Table 6 shoved the main performances of the two machines adopted for digging and separation phases for two densities evaluated. The original aspects emerged concern the difference from machine trailed and mounted with improve for the last type. Similar Effective field capacity for different machine with or without unloading phase necessary for completed the working harvest of peanuts. The yield from all production are unloaded in plastic big-bag specific for sowing seed production.

Table 6. Time and performance characteristics for 2 densities.

Parameter	D1				D2			
	Digger inverter		Separation		Digger inverter		Separation	
	Value	%	Value	%	Value	%	Value	%
Effective time (TE), s	2754	81.48	2295	59.83	2898.947	79.80	2343.83	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	3379.91	100	3835.91	100	3632.58	100	3844.28	100
Effective Speed, kmh^{-1}	4		4,8		3.8		4.7	
Operating Speed, kmh^{-1}	3.26		2,87		3.03		2.87	
Effective Field Capacity hah^{-1}	0.49		0,43		0.45		0.43	
Material capacity, t h^{-1}	2.57				1.98			

The effect of planting density on harvesting efficiency in terms of the quality of the obtained product present significant difference also for material capacity which exceed 0.5 th^{-1}.

In terms of seed quality from our results, reported in Table 7, 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 (D1) resulted in an average percentage of healthy pods of 70%, while the higher planting density (D2) recorded an average percentage of 59%.

These results indicate that 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 D1 planting density, compared to the D2 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 D1 planting density, compared to the D2 density.

A lower plant density seems to facilitate the work of the separator, and these results are in line with a study conducted by [30], who suggests that a high volume of material along the cylinder axis of the separator can increase the percentage of pod damage and cause higher losses. Therefore, our research provides further evidence supporting the importance of planting density in maximizing the efficiency of the harvesting operation and the quality of the obtained product.

Table 7. Quality of mechanical harvest (referred 1000 g of sample).

	D1	D2	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 ($P > 0.05$).

5. Conclusions

The experience has made it possible to evaluate the introduction of peanut cultivation in Campania with modern mechanized harvesting technologies. The seed density showed important aspects form yield, machine efficiency and quality of product obtained, excavation and separation operations did not highlight any criticalities while losses remained a particular aspect on which to focus for the new tests necessary to adapt agronomic techniques and technologies available to meet current market needs.

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