DOI: 10.12895/jaeid.20211.1436

Mechanically assisted harvesting of dry and semi-dry dates of average to low quality

AHMED NOURANI[1], FRANCESCO GARBATI PEGNA[2*], ANGELO ROMANO[2]

[1] *Scientific and Technical Research Center on Arid Regions (CRSTRA), Biskra, Algeria*

[2] *Department of Agriculture, Food, Environment and Forestry (DAGRI), University of Florence, Italy;*

[*] *Correspondence details: francesco.garbati@unifi.it*

Submitted on: 2020, 1 December; accepted on 2021, April 22. Section: Research Papers

Abstract: A large number of date palms in the world produce average to low quality dates that are used for processing into derivate or as animal feed and constitute an important source of sugar and energy; most of these dates are of the dry or semidry kind, so they can bear the shock of being harvested by shaking and dropping on the ground without losing their value. In order to evaluate the possibility of using hand carried electromechanical harvesters, of the type used for harvesting olives and other fruits, for collecting dates of Mech Degla and Deglet Noor varieties, preliminary field tests have been carried out at Biskra, in Algeria, with the use of two models of Italian olive harvesters, that were able to detach all fruits from a single bunch in a time ranging from 30 to 88 s, with a productivity in the range of 22.8 - 36.4 $kg{*}min^{-1}$. These results are encouraging and allow for further investigation, even with a more complex experimental design, including adaptation of the equipment to the specific context.

Keywords: *date palm fruits; manual harvesting; vibration harvesting; electro-mechanical hand harvesters.*

Introduction

The date palm (*Phoenix dactylifera* L.) has been a tree of vital importance for the inhabitants of the desert areas of the Near East, Maghreb and of the oases of the Arabic region and reference to its' cultivation go back 8,000 years (Bärtels, 2005). All parts of the tree are usable, making in the past this plant a precious resource. The fruits can be eaten fresh or dried, fermented or prepared into jam and sweets, they can be pressed to make a long lasting cake, grinded into flour and so used as an ingredient for making bread, mashed to make a paste or cooked and pressed to make a drink that can be further concentrated into a syrup similar to honey. They can also be fed to animals, together with the seeds, that can also be roasted and grinded into a drink that is used as a coffee substitute. The leaves can be used to feed the livestock or weaved into braids and used for making roofs. The trunks provide wood for construction and can be tapped for the sap. Nowadays date palms are mostly grown for the production of the fruits that are consumed locally or exported all over the world as a dessert, a diet component, for ceremonies and as an ingredient of breakfast mixes, though a large part of the average quality production is still used for the production of syrup, paste and other derivate or as an integrator of animals' feed. Date syrup can be consumed as such or used for producing sugar, alcohol or yeast (Barreveld, 1993).

The date palm can reach a height of about 36 m, but usually it does not exceed 15–20 m though, being a slow growing plant, in the first 10-15 years of full production the fruits are usually bore at a height that is never above 5 m (Zaid and de Wet, 2002).

According to FAO (FAOSTAT, 2019) the five main date producing countries in 2017 were Egypt (1,590 Mt), Iran (1,185 Mt), Algeria (1,059 Mt), Saudi Arabia (755 Mt) and Iraq (619 Mt), representing together 64% of the world production. The unit production in these countries are 32.16, 6.98, 6.31, 6.98 and 1.69 t/ha respectively.

Dates are harvested in different ways, but the most common technique remains the picking of the fruits by hand, one by one, or cutting the whole stalk and dropping it or lowering it to the ground. The harvesting method depends on the variety and the destination of the fruits, since soft and valuable fruits for fresh market need much more attention than dry or lower quality ones, being the market value the most determinant factor. Normally the harvester reaches the fruits by climbing up the trunk or with the use of ladders, lifting platforms or other means, depending on the palm height, the farm management and the plantation layout. In the first case harvest is completely manual while, when machines are used, it is semi-mechanized or mechanically assisted. Manual harvesting represents the higher cost of the whole chain (Abounajmi, 2004) and, though if compared to semi-mechanized harvest it requires little investment and is the only option in old style groves, it is still a costly[1], risky and hard operation.

Mechanization of date harvest mainly aims at addressing the cost and scarcity of specialized labor, the hazard and the burden of the palm climbing operation and is practically the only option where date palms are cultivated in large specialized plantations. However, date harvest mechanization can only be partially achieved and is based on facilitating machines, mainly ladders, lifters or platforms, that allow the harvesters to reach up to the fruit bunches level (Garbati Pegna, Battaglia and Bergesio, 2012; Nourani, Garbati Pegna, Kaci and Kadri, 2017; Bonechi, Garbati Pegna and Bonaiuti, 2018), though lower quality fruits can be collected from the ground, after shaking the whole palm or the single bunches, with vibrating heads similar to those used in harvesting of olives (*Olea europaea* L.). Akyurt, Rehbini, Bogis, and Aljinaidi (2002) and Mostaan (2016) describe main obstacles for date palm mechanization stating that in the past 5 decades no remarkable progress has been achieved in date harvesting if compared to the efforts done.

One of the main obstacles to a complete automation of this operation is the fragility of the fruits, that are susceptible of bruises and injuries that can severely hinder their value and shelf-life, so hand picking is the most common way for the valuable varieties.

However, a quite large amount of the dates yearly harvested in many countries in the world, especially those where date palm cultivation is an ancient practice and traditional groves with old or hybrid varieties are common, has a low market value and is used for processing or animal feed. In particular, dates for production of syrup can be of dry or semidry varieties and can be collected on the ground, since are less prone to damage. This allows to consider the possibility of a completely mechanized harvesting method by the use of shakers or beaters, that would have, beyond the advantages of mechanization, those of a more rational and efficient operation, since each palm could be harvested only once and fruits collected on a mat and immediately removed and stored with great improvement of hygiene and quality.

In the past Ziv, Sarig, Abramovitz and Egozi (1989) tested an inertial shaker for shaking the whole palm trunk, while Abounajmi and Loghavi, (2001) built a date bunch shaker prototype in order to study date shaking dynamics and the effect of frequency and amplitude on fruit detachment, showing that 300 cpm and 60 mm amplitude is able to effectively detach ripe fruits of the *Shahani* variety without damage and without affecting the unripe ones. More recently, starting from 2010, in some groves of the Jordan Valley, high quality dates have been collected with the use of shaking heads mounted on telescopic forklifts (Geotyltd, 2010), but the bunches needed to be previously bagged in order to collect the falling fruits; the bags were emptied after the shaking through an opening on the bottom. In this way the picking operation was made much faster but there was still need to access the fruit level for bagging the bunches and collecting the dates, and this was done with the use of expensive lifting platforms, and had to be repeated for scalar ripening varieties. This method however was abandoned, mainly because it didn't assure lack of damage to the fruits (A. Dank, 2021, personal communication, 3 February).

Harvesting with vibrating machines (mainly shakers or beaters), has been throughout investigated for the olive sector and also for other fruits, such as sweet cherries (*Prunus avium* L.) and blueberries (*Vaccinium corymbosum* L.), so much information is available and various equipment has been developed (Chen *et al*, 2012, Ferguson *et al*, 2010, Hu, Yang, Andrews, Li and Takeda, 2017, Takeda *et al*, 2017, Vieri and Zimballatti 2012, Zhou *et al.* 2016). Olive mechanized harvesting can be carried out in various way, all based on the inertia principle, where fruits are accelerated through a vibrating device clamped to the trunk or the branches or by tossing or combing the fruits directly; being this principle applicable also to dates, it could be possible to transfer this experience to the date harvesting sector and take advantage of the existing equipment already available in the market.

To date no study is available on the use of olive hand held vibrating equipment for date harvesting and particularly of those based on oscillating combs; this study aims at giving a first contribute in evaluating the feasibility of using portable motorized olive harvesters for harvesting dry or semidry dates, in order to understand if the practice can be successfully applied in smaller or traditional farms, where the amount or the value of the product don't allow for larger investments in mechanization. In this case harvesting can be done, as for olives, by laying a net under the tree and vibrating the bunches directly from the ground: the commercial value of dry and semidry dates, whose destination is processing, will not be affected by this harvesting method. This method can also constitute a practical alternative for those farmers unable to harvest timely, according to the best market conditions, due to labor unavailability. Another important advantage of hand-held harvesting systems is that they allow almost all the fruits to be removed because they can be operated around the whole target for the time the operator considers sufficient for his scope (Sola-Guirado et al, 2014).

The aim of the experiment, focused on the harvesting capacity in terms of mass $*$ time^{-1} of three different vibrating harvesting heads on two date varieties, was to verify the actual possibility of using this method for harvesting dates and hence to provide first basic information for understanding its' dynamics.

Materials and methods

The experiments have been carried out from November 11 to 16, 2018 with two different electromechanical shakers, on date palms (*Phoenix dactylifera* L.) of *Mech Degla* and *Deglet Noor* varieties, grown at the Bio-resources Station "El Outaya" (34° 55' 44.9" N, 5° 39' 00.1" E), located 12 km north of C.R.S.T.R.A. (Scientific and Technical Research Center on Arid Regions) in Biskra (Algeria).

Palms and fruits

In the selected plot, characterized by flat layout, the palms were 11 years old and 1.5 m high[2] (stem height) and planted at a 7 x 7 m distance in square holes of 3 m side and 1 m deep, in order to be protected from the wind in the early stages of their life. The holes have been gradually filled up during the palm growth. The irrigation is done by flooding the holes, pipes are in polyvinyl chloride and buried a few centimeters deep.

Palms were not well tended and fruit bunches were tangled with the unpruned lower leafs, while weeds and shrubs infested the wholes around the stem base. This situation is quite common for palms of less value, such as those whose fruits are used for processing or animal feed; in this case excessive vegetation hindered the mat positioning and access for bunch shaking and fruit collection operations so fronds and weeds were partially thinned with the use of a sickle.

Mech Degla fruits were all fully ripe (*tamr* stage) while *Deglet Noor* were partially in early *tamr* and partially in the previous *rutab* stage[3]. The palms carried from 5 to 9 bunches each, *Deglet Noor* bunches were carried more externally then *Mech Degla*. The *Deglet Noor* cultivar growing at El Outaya was described as a low quality local ecotype. All palms appeared in good conditions and no physical anomaly was observed, though the yield was generally low.

Harvesters

Two models of olive electromechanical harvesting heads, Alice Top and Holly, both equipped with oscillating combs and produced by Campagnola Srl, Zola Predosa, Italy, were tested. Both heads, which differ for the beating system (figure 1), are provided with their own electric motor and can be carried at the end of an aluminum telescopic pole, extensible up to 2.2 m. The characteristics of the 2 harvesters, are resumed in table 1.

Figure 1 - Holly (left) and Alice (right) heads

Table 1 - Technical characteristics of the two harvester models

MODEL	ALICE TOP	HOLLY
Structure	2 opposed combs moving one towards the other with 11 teeth each (6 long and 5 short, alternated).	1 comb with 10 (6 long and 4 short) teeth disposed in 2 rows.
Movement	elliptical trace	elliptical trace
Teeth length (mm)	long 245 mm, short 120 mm	long 245 mm, short 190 mm
Teeth material	flexible techno polymer	high resistance tech.polymer
weight (kg)	2,8	2,6
Oscillation frequency (Hz)	18 or 19 (selectable)	20
Motor power (W)	550	450
Energy consumption (Ah)	7-8	8-9

Journal of Agriculture and Environment for International Development - JAEID 2021, 115 (1): 85-96
DOI: 10.12895/jaeid.20211.1436

The harvesters were powered by a common 12 V, 75 Ah lead acid battery, connected to the device through a 13 m cable and converter.

Other material

4 x 4 m, plastic tarpaulin
Plastic boxes.
Field scale Zenati Electronics.
Ohaus Adventurer AX822/E Digital Scale (Ohaus Corporation, Parsippany, NJ USA)
Analogic caliper

Preliminary tests

There are different ways of using the harvesting heads for vibrating the dates in a bunch, i.e. starting from the top or from the bottom of the bunch, working randomly or sectorial, etc., so some preliminary tests have been carried out in order to choose the best method. These tests have been done empirically and results have been evaluated only by critical observation; figure 2 shows the Holly head during the preliminary tests.

Figure 2 - preliminary tests with Holly head

Vibrating the lower section of the bunch first, with a downward movement and proceeding with the one above and so on, in sequence, gives the best results, since most fruits drop vertically on the ground while, if starting from the top, a large amount of fruits is projected far away, especially from the lower sections, due to the oscillation of the bunch. Starting from the middle of the bunch has an effect in between, so the first method has been chosen: though it is slower in the vibrating phase, due to the discontinuity of the operation and to the need of combing the bunch with a sinusoidal movement, the phase of collecting the fruits from the ground is faster and the yield is higher.

Tests

The Alice Top head has been used at the 19 Hz frequency in order to better compare it with the Holly head. The Alice Top head has been tested either with the standard configuration (i.e. 2 combs) but also with only one comb, with a metal rod to replace the missing comb hence counterbalancing the one left on the head and reducing the unwanted vibrations on the pole (figure 3). A total number of 30 tests has been carried out, 15 for each variety, with 10 repetitions for each harvester configuration (Holly, Alice Top 2 combs, Alice Top 1 comb) as shown in table 2.

Figure 3 - Alice Top head modified with only one comb

Table 2 - Test scheme

TEST N.	VIBRATING HEAD TYPE	DATE VARIETY
1-5	Holly	Mech Degla
6-10	Alice Top 2	Mech Degla
11-15	Alice Top 1	Mech Degla
16-20	Holly	Deglet Noor
21-25	Alice Top 2	Deglet Noor
26-30	Alice Top 1	Deglet Noor

Each test (i.e. harvesting of 1 bunch) was divided in 3 phases:

a - First 30 s;

b - Following 10 s;

c - Completion of the harvesting (at end: no dates left on the bunch).

so a total number of 90 values was recorded.

At the end of each phase the harvested dates were collected and weighted. The time needed for the third phase (end) was recorded. From each batch a sample of 5% by weight was taken randomly and out of this, a sample of 20% by number (minimum 5 dates) was used for measuring the weight in order to understand possible relationship with detachment time. Moisture content could not be measured though ripe fruit of Deglet Noor cultivar usually contain less than 30% moisture and are generally harvested when the moisture gets below 20% (Rygg, 1975) while dates of Mech Degla cultivar harvested in similar conditions but used for different experiments had a mean moisture content of 13.9%.

Statistical Analysis

Data were analyzed using ANOVA with the GLM procedure (SAS, 2012) using: Variety (2 levels), Head type (3 levels) and Replications (5 levels) as discrete effects; interaction between "Head type x Variety" was also tested. Differences between means were tested with Student's t-test and a p-value significance level set at 0.05.

Results and discussion

Table 3 resumes the results of the 6 series of 5 tests in terms of total and mean harvested mass and relevant harvesting efficiency (percentage on total harvested) for each series, at the different time intervals, together with the total harvesting time

Table 3a - total harvested quantities and vibration time for each tested bunch (30 s = first 30 s, +10 s = following 10 s, end = completion of harvesting)

	TEST N.											
RESULTS	1-5		6-10		11-15		16-20		21-25		26-30	
	kg	%	kg	%	kg	%	kg	%	kg	%	kg	%
harvested at 30 s	12.609	79.23	12.325	83.17	15.385	89.90	18.180	85.16	16.350	96.52	11.411	85.30
harvested at +10 s	1.689	10.61	2.020	13.63	1.582	9.25	1.258	5.89	0.590	3.48	1.641	12.26
harvested at end	1.616	10.15	0.475	3.20	0.145	0.85	1.911	8.95	-	-	0.326	2.44
Total harvested	15.914	100	14.820	100	17.112	100	21.349	100	16.940	100	13.378	100
Min and max total harvesting time	30-75 s		30-66 s		30-63 s		30-88 s		30-40 s		30-63 s	

Table 3b - mean harvested quantities and vibration time for each tested bunch (30 s = first 30 s, +10 s = following 10 s, end = completion of harvesting; s.d. = standard deviation)

	TEST N.											
RESULTS	1-5		6-10		11-15		16-20		21-25		26-30	
	kg	s.d.	kg	s.d.	kg	s.d.	kg	s.d.	kg	s.d.	kg	s.d.
harvested at 30 s	2.522	0.437	2.465	0.958	3.077	89.90	3.636	1.512	3.270	0.622	2.282	0.286
harvested at +10 s	0.338	0.198	0.404	0.519	0.316	9.25	0.252	0.503	0.118	0.236	0.328	0.328
harvested at end	0.323	0.397	0.095	0.079	0.029	0.85	0.382	0.764	0	0	0.065	0.065
Total harvested	3.183	0.923	2.964	1.235	3.422	1.706	4.270	1.974	3.388	0.720	2.676	1.030
Harvesting time	50.2 s		49.0 s		43.0 s		40.8 s		21.0 s		36.6 s	

The table shows how the percentage of dates harvested in the first 30 s varies from 79.2 to 96.5 %, with most results in the range of 83.2 – 85.3, while in the following 10 s, in 4 groups of tests out of 6, the collected amount is below 5% and in remaining 2 in the range of 9-10 % and the maximum mean harvesting time for these bunches is 50.2 s.

In some tests all the fruits dropped within the first 30 s due probably to the more advanced ripening stage of the single bunches.

About 10 – 20% of dates didn’t drop on the ground but were caught in the leaf petiole bases left on the stipe, these were not considered in the count.

Table 4 reports the mean weight of the harvested dates and shows that for the Mech Degla variety (mean weight = 4.26 g/fruit^{-1}) there is no relation between the weight of the dates and the moment they drop during vibration while the heavier Deglet Noor dates (mean weight = 8.21 g/fruit^{-1}) tend to detach faster, as shown in table 3, though lighter fruits normally drop faster than heavier ones. Lighter dates of same variety might be at a riper stage, hence drier, while heavier ones have more inertia but could be more elastic due to the higher moisture, and more firmly attached due to the earlier ripening stage.

Table 4 - Mean weight of dates harvested in the 3 time intervals

	TEST N					
RESULTS	1-5	6-10	11-15	16-20	21-25	26-30
harvested at 30 s (g/fruit^{-1})	3.97	4.24	5.10	8.70	8.29	7.23
harvested from 30 s to 40 s (g/fruit^{-1})	3.90	3.74	4.56	7.64	10.24	8.78
harvested from 40 s to end (g/fruit^{-1})	4.31	4.05	4.36	8.14	-	-
Total harvested (g/fruit^{-1})	4.01	4.05	4.84	8.471	8.62	7.49

Tables 5 and 6 show the effects of head and variety on the harvesting efficiency, while table 7 shows the effect of the interaction between variety and head.

Table 5 - Effect of harvester type on harvesting efficiency at the 3 time intervals (AT2 = Alice Top with 2 combs, AT1 = Alice Top with 1 comb, HLY = Holly; 30 s = first 30 s, +10 s = following 10 s, end = completion of harvesting; s.e. = standard error)

HEAD	HARVESTED DATES (% ON TOTAL) AND STANDARD ERROR					
	30 s	s.e.	+ 10 s	s.e.	end	s.e.
AT2	92.01a	4.77	6.67a	3.53	1.34a	2.23
AT1	91.38a	4.77	7.53a	3.53	1.09a	2.23
HLY	86.31a	4.77	7.10a	3.53	6.64a	2.23

Means with different letters are significantly different (P<0.05)

Table 6 - Effect of variety on harvesting efficiency at the 3 time intervals (MD = Mech Degla, DN= Deglet Noor; 30 s = first 30 s, +10 s = following 10 s, end = completion of harvesting; s.e. = standard error)

VARIETY	HARVESTED DATES (% ON TOTAL) AND STANDARD ERROR					
	30 s	s.e.	+10 s	s.e.	end	s.e.
MD	86.79a	3.89	9.61a	2.73	3.63a	1.82
DN	93.01a	3.89	4.58a	2.73	2.42a	1.82

Means with different letters are significantly different (P<0.05)

Table 7 - Effect of the interaction between harvester type and vibration time (AT2 = Alice Top with 2 combs, AT1 = Alice Top with 1 comb, HLY = Holly*; 30 s = first 30 s, +10 s = following 10 s, end = completion of harvesting; s.e. = standard error)*

VARIETY*HEAD	HARVESTED DATES (% ON TOTAL) AND STANDARD ERROR					
	30 s	s.e.	+10 s	s.e.	end	s.e.
DN*AT1	91.48a	6.75	7.05a	4.74	1.47a	3.16
DN*AT2	97.02a	6.75	2.92a	4.74	0.10a	3.16
DN*HLY	90.53a	6.75	3.78a	4.74	5.70a	3.16
MD*AT1	91.27a	6.75	8.01a	4.74	0.71a	3.16
MD*AT2	87.00a	6.75	10.42a	4.74	2.59a	3.16
MD*HLY	82.09a	6.75	10.41a	4.74	7.57	3.16

Means with different letters are significantly different (P<0.05)

The results show how there are little differences between the three heads and the two varieties that have been tested and that the majority of the fruits fall within the first 30 s.

Concerning the harvesting capacity of the 3 heads, table 8 provides a general idea of this figure: in this case only the amount harvested in the first 30 s and in the following 10 s has been considered for the Mech Degla variety, since in some cases all dates dropped within this time; for the Deglet Noor variety only the first 30 s have been considered for the same reason.

Table 8 - Harvesting capacity of the 3 heads (30 s = first 30 s, +10 s = following 10 s)

RESULTS	TEST N.											
	1-5		6-10		11-15		16-20		21-25		26-30	
harvested	(kg)	(kg·min^{-1})	(kg)	(kg·min^{-1})	(kg)	(kg·min^{-1})	(kg)	(kg·min^{-1})	(kg)	(kg·min^{-1})	(kg)	(kg·min^{-1})
30 s	12.61	25.22	12.33	24.65	15.39	30.77	18.18	36.36	16.35	32.70	11,41	22.82
+ 10 s	1.69	10.14	2.02	12.12	1.58	9.49	-	-	-	-	-	-

Table 8 shows how the harvesting capacity was in the range of 22.8 – 36.4 kg·min^{-1} with no particular relation to the head type, so this information can be useful only for a basic forecasting of the productivity of this type of mechanical harvesting. Time needed for setting up the worksite and time losses have not been measured but these results appear to be similar to those of 450 kg day^{-1} men^{-1} recorded by Ferguson *et al.* (2010) for olive harvesting.

The characteristic of being the first test performed on this subject has concentrated the authors' interest in the actual feasibility of the process, leaving the task of qualitative and quantitative characterization to subsequent trials. Authors that have worked on mechanically assisted harvesting agree in maintaining they are an affordable mean of increasing significantly labor productivity (Ampatzidis and Whiting, 2012; Hu *et al.*, 2017; Takeda *et al.*, 2017; Vieri and Zimballatti, 2012; Zhou *et al.*, 2016) and that the main drawback is possible damage to the fruits (Hu *et al.*, 2017; Takeda *et al.*, 2017) which, in our case, is of minor concern.

Regarding the harvesting work, parameters such as time distribution, harvest rate, fruit removal efficiency and fruit catching rate can be measured (Zhou *et al.*, 2016) but in our case only the harvested weight and harvesting time were measured (Hu *et al.*, 2017).

Empirically it has been noted that the time for completing the collection of all fruits in a bunch depends mainly on the bunch size, the ripening stage and in its accessibility. However, it is interesting to note that this method has reached a harvesting efficiency of 100%, which is rarely achievable for other crops (e.g. olives) (Sola-Guirado et al, 2014).

Though the performances of the 3 heads have been quite similar, the Alice Top model caused a larger number of dates to fall out of the tarpaulin, though this amount has not been recorded, probably due to the particularity of its' movement; furthermore, the version with only one comb was uncomfortable to use because of the excessive vibrations on the pole. The Holly head instead made the dates fall vertically on the tarpaulin with almost no losses. These differences, though not quantified, are important in evaluating the tool performances since, as found by Zhou *et al.* (2017) for sweet cherry harvesting, the shaking time itself only accounts for a small part of the harvesting time.

Conclusions

The main goal of this study was to provide a first contribution in understanding the feasibility of using electromechanical manual harvesters, designed for use in olive harvesting, for collecting average to low quality dry or semi-dry dates from palms and to propose a methodology for carrying out this kind of evaluation.

The novelty of the work and some constraints in season, timing and working conditions have not allowed a completely sound experimental design, being main flaws the miss of evaluation of the ripening point of the fruits and the losses of fruits not intercepted by the tarpaulin.

However, the results show that it is possible to collect the whole production of the tested palms in quite a short time, with no risk and reduced fatigue for the operator, and with moderate losses, though only estimated, provided that the bunches are accessible and the soil under the palm is fairly clean. The positioning of the bunches is not crucial though in some cases some dates can be caught in the leaf petioles or scars on the trunk. When time is a limitation (scarce time or high hourly cost of labor) and the value of the dates is low, 30-40 s per bunch could be forecasted for achieving a satisfactory harvesting output, while in the opposite case, 1 min should be considered. Besides the time issue this method should be generally cheaper than others based on palm climbing, for the lower cost of the labor and less dangerous. The performance of the different heads was quite similar, though the "Holly" head gave slightly lower results in terms of working capacity but performed better in terms of not scattering the dates out of the tarpaulin. The Holly head is also the lighter and simplest one of the three.

Concerning any possible damage or other negative effect to the palms, the fact that the combs act directly on the fruits or on the stalk, which loses its function and ends its life cycle after harvest, allow to imagine that there are none or that are very limited.

Further studies could point out how to develop, refine and make more efficient this technique that, given the length of the poles actually available, allows to harvest fruit bunches up to a height of 3.5 m or more if the terrain allows to use a footboard safely. The electromechanical harvesters could also be used from an elevator, hence increasing their usability. Large part of the time losses in the related workings is due to the placing and removal of the tarpaulin that could be reduced by designing one specifically for date palm harvesting.

All this allows to imagine the vibration harvesting as a viable technique for harvesting dates that are not susceptible to damage when dropping on the ground or that are destined to prompt processing, hence making worth further investigation and development of this technique

Authors' Contributions

Francesco Garbati Pegna designed and supervised the work, collaborated in the literature review and in interpreting and checking the results. Ahmed Nourani organized the trials and participated in collecting and analyzing the data, in interpreting the results and in writing and checking the paper. Angelo Romano participated in collecting and analyzing the data, and in interpreting the results. All authors have participated jointly to the discussion and read and approved the final manuscript.

Acknowledgement

The authors thank Campagnola Srl for kindly making available the 2 models of harvesters and providing technical instructions to the operators and the Algerian General Directorate of Scientific Research and Technological Development (DGRSDT) for facilitating the field trials.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

Abounajmi, M. (2004). Mechanization of dates fruit harvesting. In ASAE Annual Meeting, Paper number 041028. Ottawa, CAN

Abounajmi, M., Loghavi, M. (2001). Design and development of a bunch shaker for vibratory date detachment. In Proceedings of the Second International Conference on Date Palms, Al-Ain, UAE. United Arab Emirates University (pp. 768-783).

Akyurt, M., Rehbini, E., Bogis, H., & Aljinaidi, A.A. (2002). A survey of mechanization efforts on date palm crown operations. In Proceedings of The 6th Saudi Engineering Conference, KFUPM Vol. 5. (pp. 475-489), Dhahran, SAU.

Barreveld, W.H. (1993). Date palm products. FAO Agricultural Services Bulletin No.101. Rome, ITA: FAO.

Bärtels, A. (2005). *Plantas tropicales: ornamentales y útiles*. Barcelona, ESP: Ediciones Omega.

Bonechi, F., Garbati Pegna, F., & Bonaiuti, E. (2018). Performance evaluation of an off-road light aerial platform for date palm cultivation. Sixth International Date Palm Conference. Abu Dhabi.

Chen, D., Du, X., Zhang, Q., Whiting, M.D., Scharf, P.A., & Wang, S., (2012). Performance evaluation of mechanical cherry harvesters for fresh market grade fruits. Appl. Eng. Agric. 28, 483-489.

FAOSTAT. Retrieved on January 28, 2019 from: http://www.fao.org/faostat/en/#data/QC.

Ferguson, L., Rosa, U.A., Castro-Garcia, S., Lee, S.M., Guinard, J.X., Burns, J., Krueger, W.H., O'Connell, N.V. & Glozer, K. (2010). Mechanical harvesting of California table and oil olives. Adv. Hort. Sci. 24(1): 53-63.

Garbati Pegna, F., Battaglia, M., & Bergesio C. (2012). Italian machinery and equipment for date palm field operations. Firenze, ITA: University of Florence. Retrieved on April 20, 2020 from: https://issuu.com/deistaf/docs/italian_equipment_for_date_palm_field_operations.

Geotyltd. (17 October 2010). Harvesting Medjool dates by shaking [Video file]. Retrieved from https://www.youtube.com/watch?v=05n3U95e7PY&t=1s

Hu, B., Yang, W.Q., Andrews, H., Li, C. & Takeda, F. (2017). Towards a semi-mechanical harvesting platform system for harvesting blueberries with fresh-market quality. Acta Hortic. 1180, 335-340.

Mostaan, A. (2016). Framework to develop the mechanisation of date palm cultivation. Biosyst. Eng. 147: 26-38.

Nourani, A., Garbati Pegna, F., Kaci, F., & Kadri A. (2017). Design of a portable dates cluster harvesting machine. AMA-Agr Mech Asia Af. 48(1): 18-21.

Rygg, G.L. (1975). Date Development, Handling, and Packing in the United States. Agriculture Handbook No. 482, Agricultural Research Service, United States Department of Agriculture, Washington, D.C.

Sola-Guirado, R. R., Castro-García, S., Blanco-Roldán, G. L., Jiménez-Jiménez, F., Castillo-Ruiz, F. J., & Gil-Ribes, J. A. (2014). Traditional olive tree response to oil olive harvesting technologies. Biosystems Engineering, 118, 186-193.

Takeda, F., Yang, W. Q., Li, C., Freivalds, A., Sung, K., Xu, R., Hu, B., Williamson, J., & Sargent, S. (2017). Applying new technologies to transform blueberry harvesting. Agronomy, *7*(2), [33]. https://doi.org/10.3390/agronomy7020033.

Vieri, M., & Zimbalatti, G. (2012). La meccanizzazione dell'olivicoltura italiana. Collana divulgativa dell'Accademia, vol. XV. Spoleto, ITA: Accademia Nazionale dell'Olivo e dell'Olio.

Zaid, P., & de Wet, F. (2002). Botanical and systematic description of the date palm. In A. Zaid and E. J. Arias-Jiménez (eds.), *Date palm cultivation*. FAO Plant Production and Protection Paper 156. Rome, ITA: FAO

Zhou, J., He L., Whiting, M., Amatya, S., Larbi, P.A., Karkee, M., & Zhang, Q. (2016). Field evaluation of a mechanical-assist cherry harvesting system, Engineering in Agriculture, Environment and Food, http://dx.doi.org/10.1016/j.eaef.2016.05.003

Ziv, G., Sarig Y., Abramovitz, B., & Egozi, H. (1989). An integrated mechanical system for date orchard operations. In ASAE Summer Meeting, CSAE/ASAE paper No. 89-1069. Québec, CAN.

[1] *Authors refer that in 2020 the cost of manual harvesting of Deglet Noor dates in the Biskra Region of Algeria was about 10 euro/hour*

[2] *These palms were the only ones safely accessible in the area; their low height didn't however influence the study of the effect of the devices on the bunches though, obviously, they would normally be harvested by hand.*

[3] *Rutab and tamr are the last two stages of the commercial ripening process of dates, characterized from the progressive darkening of the color, decrease of moisture and softening of the flesh (Barreveld, 1993).*