ISSN: 0128-7680
Pertanika J. Sci. & Technol. 15(1): 15 - 23 (2007) © Universiti Putra Malaysia Press

Performance Evaluation of a Terrain-Accommodating Oil Palm Loose Fruit Collector

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Received: 19 May 2003

ABSTRAK

Sebuah pemungut buah kelapa sawit terlerai jenis rantai dan jari pengaut telah direka bentuk dan dibina. Dengan kelebaran muncung 220 mm dan dua roda tukisan bergaris pusat 360mm, mesin ini boleh mengikut keadaan bentuk bumi, tumbuhan dan sisa yang berubah-ubah di sekeliling pokok kelapa sawit. Mesin diuji pada kelajuan enjin 470 psm yang menghasilkan kelajuan linear jari pengaut 52.4 m/min. Kebolehan mengutip di atas tujuh jenis permukaan dan kebolehgerakan dalam sepuluh jenis keadaan telah diuji. Penilaian kebolehan pemungut untuk mengutip menunjukkan bahawa panjang cirian (characteristic length) mesin, kelebaran serta ketinggian muncung dan kelegaan permukaan bumi-jari yang betul adalah parameter yang paling penting dalam menentukan kebolehan mesin untuk mengikut bentuk bumi. Bagi kebolehgerakan (manoeuvrability) pemungut, faktor-faktor yang mempengaruhinya adalah sokongan roda hadapan dan kedudukan roda belakang sebagai pivot. Dalam kesemua percubaan mengutip yang berjaya, mesin dapat mengutip buah tanpa sebarang kecederaan. Panjang cirian mesin menduga bentuk bumi pada peringkat makro sementara muncung pula membuatnya pada peringkat mikro. Kebolehan mesin untuk beroperasi dalam kawasan bertumbuhan dan bersisa bergantung sebahagian besarnya pada peranti pengutipan yang telah menunjukkan keupayaan menyisir kebanyakan tumbuhan dan menapis keluar sisa bersaiz kecil hingga sederhana.

ABSTRACT

A chain-and-rake type oil palm loose fruit collector was designed and developed. With a nose width of 220 mm and two 360-mm diameter wheels the machine is able to accommodate the varying conditions of terrain, vegetation and residue around an oil palm tree. The machine was tested at an engine speed of 470 rpm resulting in a linear rake speed of 52.4 m/min. Pick-up ability on seven types of surfaces and manoeuvrability in ten different conditions was tested. Evaluation of collector pick-up ability reveals that machine characteristic length, nose width and height and correct finger-ground clearance are the most important machine parameters determining the ability of the collector to follow the terrain. For collector manoeuvrability, the affecting factors are the front wheel support and location of the rear wheels as a pivot. In all successful pick-up attempts, the machine picks up the fruits free of injury. While the characteristic length negotiates the terrain at the macro level, the nose does it at the micro level. The ability of the machine to operate in areas of vegetation and residues depends largely on the picking device, which has been able to comb through most vegetation and filter out smaller to medium size residues.

Keywords: Loose fruit collector, finger-fruit interaction, terrain-accommodating, vegetation, residue

INTRODUCTION

Currently, the most effective ways of collecting loose fruits in the field are the hand and the board methods. The former entails scraping the ground with two pieces of board to gather and lift the fruits into a sack while the latter involves the same procedure but uses both hands (gloved) without the aid of board. In both methods, fruit injury is practically absent but a substantial amount of debris, small plant matter and pebbles are also collected. These non-fruit matters are separated from the fruits before the fruits are sent to the mill. Measurements made at UPM farm give a gross fruit collection rate (i.e. including all non-fruit matters) of 39.6 kg/hour. Bardaie (1987) reported that 28% of the total time required for field operations, from the cutting of the fronds to the movement of the FFB transporters to the next palm, was spent in collecting loose fruits. Earlier, Turner and Gillbanks (1974) and Webb (1977) reported that the amount of time spent to be at 25% and 39%, respectively.

Gan *et al.* (1993) reported that the average time spent to collect the fruits by hand was three minutes and this was five times the time taken to cut a fresh fruit bunch. Thus, most workers did not collect the loose fruits. Loose fruits are found not only in the fields but also at the unloading ramp. Human labour is employed to pick these fruits by hand.

At the ramp, the spread of loose fruits is confined to a small area in a relatively high concentration on flat concrete or tarred surface. Mechanised picking in this area is not a problem; in fact, the status quo is believed to be more effective and economical. The main problems faced in the use of mechanical collectors in plantations are the terrain (T), the vegetation (V) and the residue (R) in order of importance, conveniently referred to here as the TVR problems. The typical oil palm plantation has a very rough terrain. Even a flatland plantation is not flat when observed at a close range. The ground around the palm may have mounds, depressions, ridges, gullies, partially embedded rocks and loose gravels, among others. Vegetation includes grass, weeds, creepers and other undergrowths. Fruits trapped in between these plants are difficult to recover. Currently, manual picking is the only certain way of recovering them. Vegetation can be controlled relatively easily through the application of herbicides and regular use of crop upkeep equipment. Residue includes cut fronds, felled trunks, old uncollected loose fruits and debris. All these factors are a hindrance to mechanical collectors.

Various terrain, vegetation and residue characteristics are found in a plantation to give an infinite number of combinations of these elements. Even under and around a single palm loose fruits can be found in different TVR conditions, bringing up the importance of micro-terrain in design and development. The machine must be versatile enough to be able to adapt to the varying TVR requirements (micro-terrain) in order to pick up the fruits in the desired time period, free of injuries and foreign matters. However, a machine can perform only in the set range of conditions for which it is designed and developed. The small fruit size against the big terrain, vegetation and residue elements complicate the scenario, making it difficult to recover the lodged fruit. Thus, the demanding performance expected of an oil palm loose fruit collector can be appreciated.

Various collectors have been built. However, all of them suffer from the inability to accommodate the plantation terrains. They are generally too wide, could only pick up fruits on flat open ground and unable to pick up fruits near obstacles including the palm trunks. Some research carried out studied the different methods of picking rather than addressing the TVR problems. Muhammad Salih and Razak Jelani (1988) developed a cylindrical collector that collects one fruit at a time. The process is similar to individual

fruit picking by hand except that with the use of this cylinder, the labourer does not have to bend down. Mechanical collectors employing the sweep or brush mechanism were developed by Osman (1988) and Rosnita (1998). Narayanan (1992) and Harris (1995) used discs as the collecting device. Different suction methods were tested by Wan (1993), Ahmad Hitam *et al.* (1995) and Mahmud Manti (2004). The machines were big and not quite to the terrain and fruit collection rates reported were about 1.0 kg/min with debris varying between 5 and 10 %. Following that, Mohd Shahir (2006) experimented with a modified 1.2-kW domestic vacuum cleaner and managed to collect 0.64 kg/min of loose fruits under laboratory condition with debris rated at 2.1%. The whole machine weighed about 10 kg and the suction air flow rate was 4.75 m/s and reported to be insufficient. The simple method of using a gatherer and scoop was tested by Fakhrurrazy (2003) who obtained a fruit collection rate of 1.1 kg/min with 4% debris.

Although various performance levels of these machines are reported, they have yet to be used on a continuous basis. As such, no realistic indicator of performance level as a reference value can yet be available unless and until a loose fruit collector has been successfully used in a continuous manner in real field operations. An indicator obtained from simulated tests would not be representative because the real nature of loose fruit spreads on the ground upon FFB impact can never be reproduced.

There is a clear need for a collector that can be adapted to varying conditions of terrain, vegetation and residue. A prototype of such a machine is built, and being in its preliminary stage, the design and development is focused on achieving the ability to pick up fruits in different conditions rather than on its operational field performance. Hence, the present study of its performance is confined to the qualitative evaluation of its functional ability, i.e., its picking ability and manoeuvrability, detailed as follows.

1. The ability of the machine to pick up fruits free of dirt and injury
2. The ability of the machine to pick up fruits trapped in vegetation
3. The manoeuvrability of the machine on different terrains

METHODS

The collector was designed and developed with the aim of getting a low-weight machine and addressing the TVR problems. A 1-kW grass cutter engine (Tanaka SUM328) running at about 470 rpm was used as a power source. The collector is shown in *Fig. 1.*



Fig. 1: The oil palm loose fruit collector

To be able to accommodate the different terrains, the collector was built as narrow and as short as possible. This would allow it to access difficult areas such as depressions, ridges and gaps between obstacles. In order to avoid the tyres from being stuck in between small obstacles and in soft ground, a pair of large pneumatic tyres was used for traction. Two small wheels at the front served as a guide. *Fig. 2* shows the various important parts of the collector and *Fig. 3* shows the relevant dimensions in millimetres.

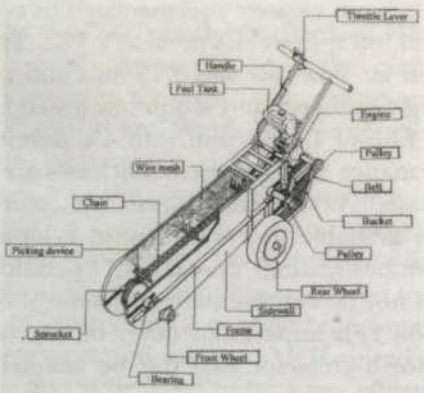

Fig. 2: Important parts of the oil palm loose fruit collector

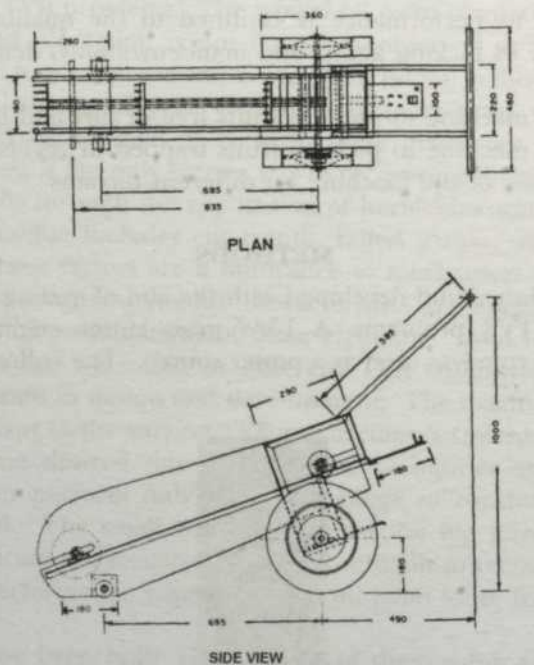

Fig. 3: Relevant dimensions of the collector in mm

Not including the handle, the total width of the machine at the rear wheels is 425 mm. The nose, i.e., the body proper part to the front of the large rear wheels (excluding the small front wheels) determines whether or not the machine can access difficult areas. This part has a width of 220 mm.

Once a difficult area is accessed, the fruit must be able to be picked up by the picking device of the collector. This device is of the continuous chain and rake type. Four steel rakes placed at equal intervals on the 1747 mm long chain travel with a linear velocity of 52.4 m/min. The rakes gather the fruits and push them up along the floor inclined horizontally at about 20° into a bucket at the end of the incline. For smoothness and to avoid rust, an aluminium sheet is used for the floor. The fingers of each rake are placed close to each other so as to avoid the fruits from slipping through and to discard small residues. A 10-mm clearance is given between the tip of the fingers and the ground to ensure the picking up of the fruits using these fingers and avoid scraping the ground. These fingers are also encased in plastic tubes to keep the fruits intact. Being of the finger type, the rakes are expected to comb through the vegetation.

The machine was tested at an engine speed of 470 rpm and a resulting linear rake speed of 52.4 m/min. The pick-up ability was tested on seven different surface categories as listed in Table 1. Description of the categories is as follows:

a) Uneven ground: gradual mounds and depressions, gentle ridges, low surfacing roots.
b) Frond-covered: the frond piles in between rows of palms.
c) Grass: ordinary grass.
d) Other vegetation: creepers, small plants, lallangs, etc.
e) Sudden depressions: holes, shallow but steep drop in surface levels, ridges.
f) Rocks/other obstacles: partially embedded rocks, step-like inclines, occasional thick standing plants and timber, areas within about 20 cm from trunks.
g) Clear: relatively even, varying from flat to about 15% slope.

The manoeuvrability was tested in ten different conditions as listed in Table 2. All tests were carried out during real harvesting operations with loose-fruit spread being formed naturally upon the impact of the FFB on the ground. Except for a number of cases on uneven ground, grass and clear areas, each pick-up attempt was usually on a single fruit.

RESULTS AND DISCUSSIONS

Picking Ability

The picking ability of the collector in the various surface categories is shown in Table 1. Uneven ground, grass and clear areas were well accommodated by the machine but it totally failed in frond-covered areas as there was no way of recovering the fruits without first lifting the bulky materials. To minimize frond-covered area loss, frond piles would have to be as far away as possible from the palms. Although the 220 mm wide nose could negotiate many terrain features, there were more gaps in the TVR surroundings narrower than the nose, preventing it from accessing the fruits trapped in them. The rakes are firmly fastened to the chain but the flexible nature of the chain allows the rakes to be not truly horizontal. This can be clearly seen in *Fig. 1*. This phenomenon is undesirable as it increases the chance of missing the fruits if they happen to be under the higher sides of the rakes.

TABLE 1
Picking ability of a terrain-accommodating loose fruit collector

Feature at pick-up areas	Total attempts	Success	Failure	
			Injured pick-up	No pick-up
Uneven ground	50	30	10	10
Frond-covered	20	0	0	20
Grass	20	16	4	0
Other vegetation	40	22	4	14
Sudden depressions	50	11	9	30
Rocks/other obstacles	33	11	6	16
Clear	60	56	4	0

The rake fingers were able to comb through grass. However, when the vegetation was of creepers or other plants that grew perpendicular to the length of the machine, they were torn off and carried into the bucket. Tougher vegetation caused the chain rotation to slow down necessitating the depression of the throttle lever to bring the engine up to speed again. Only debris larger than the rake finger spacing was conveyed along with the fruits into the collecting bucket. A slatted floor helps to minimize this problem except for debris that happens to lie across the slats.

The picking device is the most critical and sensitive part of the machine with the finger-ground clearance very much dependent upon the terrain. Zero clearance will result in the fingers scraping the ground gathering along debris or being stuck in the ground. On the other hand, too much clearance results in either the scraping of the fruits (due to partial finger-fruit interaction) leading to injuries or the fruits totally escaping the machine. Fruits that were injured were those that the fingers interacted with only partially and could not be dislodged by the first few rakes. It was the continuous action of the fingers in trying to extricate these fruits from their trapped positions that caused the injuries. Although they were eventually picked up, these fruits are considered as a failed attempt as they otherwise would have been, if not for the persistent trying by the operator of the machine. Fruits that were properly interacted with (picked up immediately) upon tilting were not injured. It was also observed that it was a natural reaction of the operator to increase speed and tilt the machine slightly forward whenever a fruit is difficult to dislodge. This is specifically so in cases of obstacles and sudden depressions which cause the fingers to be far from the fruits. Other operations such as conveying along the incline and discharging into the bucket did not cause any injury to the collected fruits.

Palm trunks were obstacles to the machine for fruits within a 20 cm distance of the trunk perimeter. This problem was due to the front end of the sidewalls extending beyond the chain boundary. From *Fig. 2*, it can be seen that it is possible to shorten the sidewalls to result in the fingers jutting out ahead of the machine. This is expected to resolve the front obstacle problems that are in other forms such as rocks, earth walls, etc.

Other factors influencing the ability of the machine to accommodate the terrain are the characteristic length and the nose height of the machine. The characteristic length is the horizontal distance between the ground contact point of the rear traction wheel

and the point at which the nose curvature contacts the ground. The shorter this distance is, the better the machine will able to be used on the different terrains.

The nose height has to be small to enable the machine to properly engage according to the ground physical feature at the pick-up spot. The height of the nose is characterized by its curvature, subsequently the distance between the tensioned and slacked sides of the chain. Reducing this curvature would entail using smaller front sprockets and shorter-fingered rakes. Subsequently, the sidewalls could also be replaced with low ones that would have to be high enough to prevent the fruits being conveyed from falling off the sides. When the nose size is considered together with a shortened characteristic length, the chain speed would also have to be changed accordingly. In short, with respect to the machine, the characteristic length accommodates the terrains at the macro level while the nose at the micro level.

Manoeuvrability

Table 2 shows the difficulty level in various manoeuvring efforts for the collector. The reference level is that of manoeuvring the collector on a firm, dry and flat natural plantation ground with thin vegetation cover. A single operator carries out all the manoeuvrability assessments.

TABLE 2
Manoeuvrability of terrain-accommodating loose fruitcollector (on two traction wheels)

Manoeuvre types	Easy	Moderate	Difficult
Going up a slope		/	
Going down a slope	/		
Cornering on a slope			/
Backing up – going up a slope	/		
Backing up – going down a slope	/		
Going over obstacles (level)	/		
Going over obstacles (slope)			/
Other movements on level surface	/		
All movements on wet and soft surface (level)		/	
All movements on wet and soft surface (slope)			/

Easy: Success is achieved on the first attempt. Operator does not feel unduly stressed in applying the effort needed. This is a typical reference level achievement.
Moderate: Success is achieved on the second attempt. Operator feels that he is applying an amount of effort over and above the reference level.
Difficult: The operation is marked by two or more failed attempts or a complete failure. Operator is stressed.

Due to the small front wheels and the nature of the plantation grounds, it was found that when not picking up fruits, moving the machine on the two rear wheels were more convenient though not necessarily relaxing. On slopes, the machine was felt heavier due to the unsuitable location of the large rear wheels making manoeuvring a problem. A better pivot position for the wheels and/or an improved handle design would make the weight balance more manageable on slopes. On softer surfaces, the front wheels tended to get stuck in the ground affecting the finger-ground clearance and the manoeuvrability

of the machine. Therefore, there was a need for big pneumatic front wheels instead of small steel rollers.

Manoeuvrability on level ground was poor when the surface was bare and wet. On such a slippery condition, the need for wider rear and front wheels was again felt. However, wider wheels would increase the width of the machine especially at the important front end, in which a proper engagement with the micro-terrain is important, as discussed above. An alternative would be to use reduced inflation pressure for the rear wheels. As for bigger front wheels, though not bigger than the rear ones, their positions beneath the inclined floor would have to be moved further backwards to retain the desired nose features. This will change the overall balance and handle design of the machine. However, it should be noted that a two-wheel machine is undesirable as it encourages operator fatigue.

CONCLUSIONS

The current terrain-accommodating loose fruit collector was able to address a major part of the TVR problems. Satisfactory picking ability was observed on uneven ground, grass and clear areas. However, the machine was found to be unsuitable in the frond-covered areas. The finger rake method of gathering and conveying fruits is successful in eliminating fruit injuries and debris. For successful picking, a correct finger-ground clearance is important to ensure adequate interaction between the fruits and fingers.

On-slope manoeuvrability is not satisfactory during cornering, overcoming obstacles and when the slope is slippery. Manoeuvrability on a level surface is only a problem if the surface is slippery. In order to improve manoeuvrability, bigger pneumatic front wheels are required and should be installed further rearwards, while relocating the rear wheels and/or redesigning the handle for a better weight balance.

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