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Study on the Sweeping Effectiveness of Oil Palm Broom form for Sustainable Domestic Applications

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

Oil palm broom as a veritable household equipment is fast going into obsolescence partly due to some technical default in their use form and partly due to the crave for some unsustainable perceived alternatives. This study investigates the domestic applications suitability of natural oil palm broom and undertakes an empirical optimisation of the sweeping effectiveness. A field survey was carried out both in urban and rural settings to ascertain the current use of palm broom compared to other synthetic and non-biodegradable equipment acting as challengers. An optimisation process was done in tying of the broom strands. The broom strand lengths and spread angles used to optimize sweeping effectiveness were, 0.2 m, 0.4 m, 0.6 m, 0.8 m and 1.0 m lengths and 10°, 25°, 50°, 75° and 90° spread angles respectively. The results show that 75° strands spread angle and 0.8 m broom length give the best sweeping effectiveness. The determined form herein is easy to use. The oil palm sweeping broom is a natural eco-friendly, cheap and sustainable indispensable cleaning tool for most households and communities due to its unique features. An efficient design of the form configuration of the oil palm sweeping broom will improve on swept area output and also lessen the arduous effects of sweeping. There is need, therefore, to encourage the science and art of its production, especially in rural areas where it has great potential economic value to enhance the standard of living of the producers.

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1. INTRODUCTION

The activity of dirt removal from main roads, streets, compounds, room floors, wall and ceiling using long bristle materials can be regarded as sweeping. Sweeping is an important household routine as well as a community work that helps keep the environment clean and habitable. Sweeping is the primary activity adopted in many countries of the world to remove wastes from homes, squares, school premises, health clinics, religious worship arenas, industrial complexes, workshops, markets and other commercial outfits [1,2]. Broom street sweeping helps to restore the permeability of paver's infiltration capacities by eliminating clogging materials [3]. A clean swept environment has a positive effect on productivity, the quality of work [4] and the overall health of the inhabitants. Unfortunately, both coarse and fine waste particulates of plant leaves, loose soils, synthetic scraps, mechanical abrasion wears and engine exhaust sooths litter our environment on a daily basis. They are generated from natural and human activity within the ecosystem. These out of place matter deface our surroundings and can cause enormous public health issues. The wind and non-wind driven resuspension particles' inhalation have been indicated to influence certain morbidity and mortality outcomes [5]. As a remedial measure, many urban solid waste management systems are made available to maintain a clean environment. The choice of the best service system takes into cognisance the environmental impact, both positive and negative. While mechanical service systems no doubt, are more effective than the manual in terms of output they surpass the manual in all negative environmental impact categories which include climate change, ozone depletion, particulate matter regeneration and land use abuse. Bartolozzi et al. [1] identified traditional manual street sweeping input equipment to include brooms, dustpans, baskets and bin liners. And based on a life cycle assessment, most of these manual equipment was described as green tools that have minimal impact on the environment. Despite the presence of other sweeping equipment and cleaning devices, brooms have remained a must-have in most homes due to their unique advantages that increase the demand as the population grows in many countries. It is most suitable for sweeping irregular surfaces and dusting wares. They are used in beating off dusts from surfaces of felt materials like bags, clothes, rugs, curtains, etc. Also, there are some intangible values of oil palm sweeping brooms as well. It can be used to create aesthetic patterns on sandy grounds to adorn the compound. Apart from sweeping and cleaning purposes, brooms are used to kill insects and drive away mosquitoes. It is also required in the performance of some religious rituals. Of recent in Nigeria, broom was displayed as a political party logo to symbolically sweep out bad governance.

Sweeping of dirt in many developing economies are done manually. It involves the bending and repetitive to and the fro motion of the hand and waist/bottom body parts. Sweeping exercise is carried-out mostly by women, especially housewives and their teenage children and wards. The wrong form of brooms increases the body stress coupled with lower sweeping output. It was posited that awkward positions and movement of the body as obtain in manual sweeping induces chronic musculoskeletal pains [4,6] just as inhalation of dust and other aerosols during sweeping pose a health challenge. In developed economies like Europe, the USA and China, sweeping robots are developed to reduce human activity involvement in cleaning jobs, especially in organized and pre-planned environments [7,8,9,10]. Nonetheless, improving the form of traditional sweeping broom would reduce the tortuosity of the sweeping exercise. In developed countries their type and art of sweeping broom production is well documented with patents, the same cannot be said for the developing countries. For instance, Satori [11] worked on form optimization of the sweeping efficiency of a hand sweeping brooms made of synthetic nylon bristle tufts. He maximized bristles contact area with the swept surface by developing an adjustable broomstick handle. Pardo [12] improved on the sweeping effectiveness of sweeping brooms by using a combination of bristles of varying stiffness and lengths at different locations within the broom head shroud. The oblique sweeping end formed by the graded length bristles coupled with a stiffer, longer one-side enabled corners and flat surfaces to be equally swept simultaneously. These modifications were however related to the synthetic, non-oil palm type of brooms and having a sophisticated shroud and handle which would have a negative effect on cost. Manual oil palm sweeping broom is the focus of the current study.

Bristle materials used for manual sweeping can be in the form of broom or brush. Brooms are majorly processed from natural materials such as oil palm frond leaf petioles (oil palm leaf-rib or broom fibre) while brushes can be made of natural grass material or synthetic plastics. While the broom comes in a form of long thin palm leaf ribs or grass spikes tied together to form a bunch, brush is a collection of short bristles fixed to a rectangular or circular wood and plastic stocks. Oil palm brooms for removing cobwebs from high walls and ceilings, and grass brooms, are produced with an extended long handle. The stock is usually fixed to a broom stick which is long cylindrical wooden or plastic material. In many African, South American and Asian countries, broom grasses (*Thysanolaena maxima*) are harvested, dried and attached to sticks for sweeping purposes. The production function is by women and girls that engage in it for economic benefits [13,14]. According to Shackleton and Campbell [15] grass broom production is a means of survival for many low educated downtrodden middle aged and elderly women in the Bushbuckridge municipality of South Africa with an estimated net yearly income of 120 USD and 60 USD for producers and middlemen respectively. Oil palm sweeping brooms are mainly processed from leaves of mature palm trees of up to 10 years to ensure acceptable length and strength (see Figs. 1 and 2).

Fig. 1. Palm tree thriving in a farmland in Nsukka, Nigeria

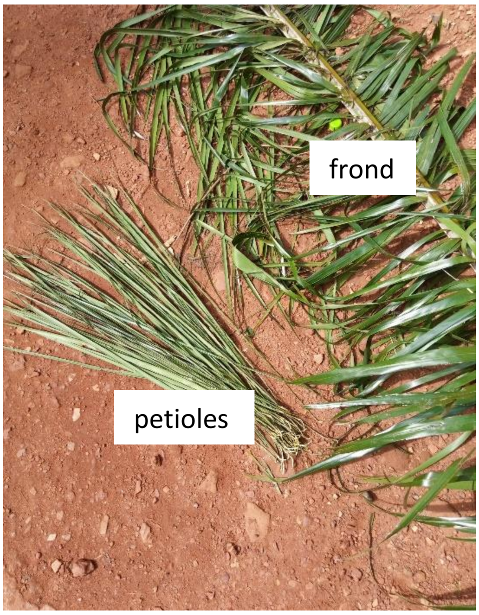

Fig. 2. Extracted palm frond leaf petioles for making broom

The production of oil palm brooms has remained largely subsistence and an itinerant village activity, probably because of the bush location of the raw materials and the inherent neglect associated with the processing activity. Nonetheless, as a natural material, it is biodegradable and therefore eco-friendly at the end of its service life. When compared to its synthetic counterpart, the natural broom is cheap, the raw material is obtained freely as a by-product, the only costs associated with it is that of transportation to the market. The production process, however, is arduous and sedentary in nature. According to Nwosu et al. [16], activity of broom processing is mostly undertaken by rural women and their children on a small scale. Though, efforts are being made to mechanize some of the activities such as the stripping process [2] especially now that expanded uses of broom strands as a reinforcement in concrete structures are being proposed. It has been shown that the addition of oil palm broom fibres in concrete improves the tensile strength, modify the brittle behaviour and reduce the cost of material input in the concrete structure [17,18,19]. In many West African countries, oil palm brooms are obtained as a waste when oil palm fruits are being harvested, or during wine tapping wherein some fronds must be cut off. Petioles are then removed from the frond, and small knives used to strip off the residual leaves from the broom strands. A collection of the stiff fibre strands is then tied together into a bunch as a broom. The sizing of the bunch varies from one processor to another. Moreover, marketers through sharp practices advertently reduce the size of the bunch in order to increase the number of bunches to be sold so as to maximize profit, thereby compromising functionality to the detriment of the end users.

The suitability of a sweeping equipment depends on the size, structure and texture of the dirt to be cleaned, the cleaning environment and the topography of the surface to be cleaned. Sweeping is done through a pushing action of the bristles, as the hand of the user swings from right to the left and vice versa repeatedly the dirt is gathered together. The movement from right to the left actuates the push action while the return from left to the right is redundant free, similar to a shaper machine operation. Unlike the plastic bristles, oil palm broom does not creep or undergo plastic deformation, but deteriorate by gradual abrasion wear at the tip. Synthetic brooms tend to flare gradually as it is being used. The elastic limit is exceeded through fatigue occasioned by continuous stress from the pushing action because of the low flexural plasticity. The oil palm broom on the other hand tends to wear down gradually from the sweeping surface/tip instead. Depending on the skill of the broom user to rotate the broom from time to time, the broom sweeping surface tends to were unevenly forming an oblique angle. The lengths of the broom bristles farther from the user being longer than the ones close to her. Therefore, the ease with which sweeping can be done using the oil palm broom is dependent on both the quality of the broom and the dexterity of the sweeper. The strength quality of the broom fibre is associated with their origin, composition, physical properties and the processing requirements [17]. The demeaning regard attached to the broom production, despite the high importance of the cleaning potential requires close examination. Brooms from natural sources are obtained from abundant renewable source, biodegradable and remains ecofriendly, and cheap. The technicalities involved in tying the broom is not universal, the bunch size, the spread angle, the broom fibre length and the strength in all affect its sweeping effectiveness. It is the objective of this study to assess the acceptability of oil palm sweeping broom as a sustainable domestic cleaning equipment and to determine the optimal form broom length and spread angle for minimum sweeping time and effectiveness.

2. METHODOLOGY

2.1 Design Considerations

The surfaces to be swept are not normally flat hence consideration is given to a broom that can sweep both smooth and rough surfaces, flat and undulated topologies. The cost of oil palm sweeping-broom has to be preferentially low to make it comparatively affordable to all low-income intended users. The physical and mechanical properties of the broom strands affect its sweeping effectiveness. Therefore, it has to possess sufficient fatigue strength to withstand frequent use under reversal bending stress. The broom cross-section, length, spread angle, operating speed, etc. are known to affect the sweeping efficiency [20]. As a manual activity the human factor of capacity and effects were accommodated. It is noted that, naturally, individuals have different sweeping rates. For uniformity of data, persons with similar sweeping rate carried out each set of experiment. From preliminary investigations, sweeping time and efficiency is affected by the amount of litter and dirt in a particular swept location. This means that locations with a high amount of dirt and litters will have a larger sweeping time and consequently a reduced broom sweeping efficiency. Hence, swept areas with a fairly uniform amount of litters and dirt were used.

The ergonomic aspect of the broom form was considered by matching the broom form to a typical user features. A typical user height of between 1.2 m to 1.8 m and hand palm average area of 0.01 m^2, and capacity to hold a sizeable bunch were taken into account in establishing an appropriate bunch stock hold diameter. A possible adaptation towards the use of one hand or two hands to hold the broom was accommodated in the design decision. The activity of sweeping was also considered a non-skilled labour and hence will not require any special training. Weather elements and changes such as wind and rain were considered as a limiting factor. Hence, the work was assumed to be done in a controlled environment.

2.2 Materials

Twenty oil palm brooms produced locally were purchased from the Ogige market at Nsukka, Nigeria at the cost of NGN 200.00 per broom bunch for experimental studies. The broom strands were made of palm fronds leaf ribs. Also one sweeping brush with synthetic bristles was procured at the cost of NGN 750.00 to ensure a fair comparison as a challenger waste cleaning equipment using the same study swept surface areas. A mixed age of regular sweepers comprising 10 women and 20 teenage boys and girls were selected for the test experiment. A variety of compound dispositions were selected for carrying out the study. These include a sandy ground compound, a concrete paved compound and a tiled surface floor. A stop-watch was obtained from the tools' store to enable accurate monitoring of the time taken for each activity.

2.3 Methods

Both subjective and objective studies were done to evaluate users' perception of oil palm broom as a cleaning equipment and its sweeping efficiency. Nsukka urban, in South east Nigeria, was chosen as the study area, as it is surrounded by satellite villages that produce oil palm brooms. Surveys were conducted through one on one interviews of illiterates while questionnaires were distributed to the literate ones. Sixty copies of the questionnaire were administered to selected literate and semi-literate members of the university community and the neighbourhood. But 58 responses were recovered and used to analyse the preferred sweeping equipment based on durability and ease of use. Data collection spans through the University of Nigeria, Nsukka community and beyond. The sample size includes students, female members of staff within the University residential quarters and house wives within Nsukka metropolis which enhanced easy management. A 3-point Likert scale chart with the level of the agreement specified as either "True", "False" or "Not Sure", was used to obtain responses. Response analysis confirmed the oil palm broom as a necessary cleaning equipment.

The experiment to determine the optimal form of sweeping broom therefore followed. Based on preliminary study and experience, the brooms were retied to get the normal bunch sizes having 600 strands each and a stock hold diameter of 50 mm. Five tufts were then cut to obtain sweeping broom lengths of 1.0 m, 0.8 m, 0.6 m, 0.4 m and 0.2 m for the sweeping exercise (see Fig. 3). For each length of broom, the average time taken to sweep a given sample area during the morning hours, for randomly chosen 3 days, was taken. Then, with the best length determined, various spread angles were used, holding the best length constant. Five brooms were each tied to obtain angles 10°, 25°, 50°, 75° and 90° respectively. A repeat of the sweeping was then carried out using the different spread angles. This is done to obtain the best length and spread angle to give a neater area with minimum time, which in turn, means obtaining a higher efficiency of sweeping.

The work took place at various locations with different ground surface terrain. Swept surface types used for the experiment are paved concrete floor, an unpaved sandy compound and tiled floor. Each floor type with a definite floor area was used for each set of experiment. Selected areas include Agbebi IV Mechanical Engineering 197.25 m^2 sandy quadrangle, Jimbazz Faculty of Biological Sciences 115.24 m^2 concrete floor and the 29.7 m^2 tiled podium of the Engineering lecture auditorium. The experiment was carried out using brooms of different lengths for different floor types. Also, another set of experiments were carried out using a specific length of broom for different spread angles of brooms. The efficiency of the broom is measured against time for each. The experiments were validated using tests performed in preselected residential homes, located at a distance away from the experimental school premises, and the sweeping by a different set of house wives with their wards.

Fig. 3. Oil palm broom length variations used for the output efficiency optimization

3. RESULTS AND DISCUSSION

The perspective performance and empirical optimization of the oil palm broom have been carried out to enable the standardization of the sweeping broom form. Data collection was done using structured and unstructured interviews, and questionnaires. This helped in the analyses of public perception concerning the natural palm broom as an important domestic tool. The result of the investigation encouraged the subsequent work to optimize the broom form for effective and efficient sweeping operation. The optimal broom length and the spread angle were then determined.

The response from the questionnaire is summarized in Table 1. Whereby 60 questionnaires were distributed only 58 of them were recovered with the survey participants' responses recorded. It shows 97% success in the questionnaire execution process. The survey interrogates the usefulness of the oil palm sweeping broom, its effectiveness as a cleaning equipment and the durability perception. The results show that it is 100% and 93% correct to assert that broom is mandatory in a home and the most used cleaning equipment respectively. The high percentage can be attributed to its availability based on local productions, affordability, easy to use and traditionally endeared home tool. The questions also adumbrated on its comparative function with regard to other competing equipment sourced overseas. Nonetheless from Table 1 it is shown that oil palm sweeping broom exerts more stress on the user than the vacuum cleaner and the sweeping brushes with 72% and 59% affirmation respectively. This may not be unconnected to the form in which the oil palm broom is used.

In Table 2 is shown the comparative analysis summary of the survey specifically interrogating the durability and the ease of use of the oil palm broom. The results show that the oil palm broom is 41% and 64% affirmed to be more durable than vacuum cleaner and sweeping brushes respectively. The high percentage of the group that is not sure making up 26% may be due to the fact that vacuum cleaners are not common in the locality. Many may not have even seen one talk more of using it. It is also observed that more than 72% and about 59% agreed that oil palm broom is easier to use than the vacuum cleaner and the sweeping brushes respectively. A similar argument of unfamiliarity and the complex nature of the vacuum cleaner which might require a training of some sort may be responsible for 12% not sure and a low 15.5% false obtained.

The effects of the length of sweeping oil palm broom are shown in Tables 3 – 5 for various swept ground surfaces. From Table 3, the sandy area swept per hour using 0.8 m broom produced the highest output of 3622 m^2/h while the 0.2 m length gave the lowest output of 2840 m^2/h. In Table 4 the 1.0 m full broom length produced the highest output of 682 m^2/h while the 0.2 m length gave the lowest output of 334 m^2/h when the concrete paved compound was swept. Likewise, in Table 5 for tiled floor, the 1.0 m broom length produced the highest output of

1125 m^2/h and subsequently decreased successively to 742 m^2/h when the 0.2 m broom length was used. It seems that the smooth surfaces of the concrete paved compound and the tiled floor favoured longer brooms as it does not require stiff bristles to move the dirt. On the other hand, the sandy compound is rough and contains loose soil with heavier debris that causes the 1.0 m length broom slender tip to flex without pushing the debris. The flexural strength is lower towards the tip because the lower aspect ratio. However, it is also observed that at moderately longer the broom strands the higher is the output. This might be associated with the ergonomic convenience of the long brooms coupled to the larger area of the broom tip in contact with the swept surface.

Table 1. The oil palm sweeping broom's questionnaire response summary

Question	True	False	Not sure
Broom is a basic and mandatory cleaning equipment in the home.	58	0	0
Broom is the most used cleaning equipment in the home.	54	3	1
Broom is the most effective cleaning equipment in the home.	26	18	14
Broom is easy to use compared to other cleaning equipment.	41	12	5
Brooms are frequently changed compared to other cleaning equipment.	29	19	10
Use of brooms during cleaning reduces time spent on cleaning in contrast to vacuum cleaner.	22	24	12
Brooms are found to be durable and long lasting compared to vacuum cleaner	24	19	15
Brooms exerts more stress on the user compared to vacuum cleaner	42	9	7
Brooms are more effective as a home cleaning equipment than the vacuum cleaner	18	31	9
Use of brooms during cleaning reduces time spent on cleaning in contrast to sweeping brushes	41	11	6
Brooms are found to be durable and long lasting compared on other sweeping brushes.	37	3	18
Brooms exerts more stress on the user compared to Sweeping brushes	34	15	9
Brooms are more effective as a home cleaning equipment than sweeping brushes	34	16	8

Table 2. Summary of the data analysis from questionnaire responses

Question	True (%)	False (%)	Not sure (%)
Durability Comparison			
Broom is more durable than a vacuum cleaner	41.37%	32.76%	25.86%
Broom is more durable than sweeping brushes	63.79%	31.03%	5.17%
Ease of Use Comparison			
Broom is easier to use compared to vacuum cleaner	72.40%	15.51%	12.06%
Broom is easier to use compared to sweeping brushes	58.60%	25.86%	15.51%

Table 3. Sweeping broom length output data for the swept area of 26.3 m by 7.5 m sandy compound

Length (m)	Time (s)	Area (m^2)	Output (m^2/h)
1.0	209	197.25	3397
0.8	196	197.25	3622
0.6	229	197.25	3100
0.4	223	197.25	3184
0.2	250	197.25	2840

Table 4. Sweeping broom length output data for the swept area of 13.4 m by 8.6 m concrete paved compound

Length (m)	Time (s)	Area (m^2)	Output (m^2/h)
1.0	608	115.24	682
0.8	770	115.24	538
0.6	845	115.24	490
0.4	1086	115.24	382
0.2	1241	115.24	334

Table 5. Sweeping broom length output data for the swept area of 11.0 m by 2.7 m tiled floor

Length (m)	Time (s)	Area (m^2)	Output (m^2/h)
1.0	95	29.7	1125
0.8	109	29.7	980
0.6	126	29.7	848
0.4	137	29.7	780
0.2	144	29.7	742

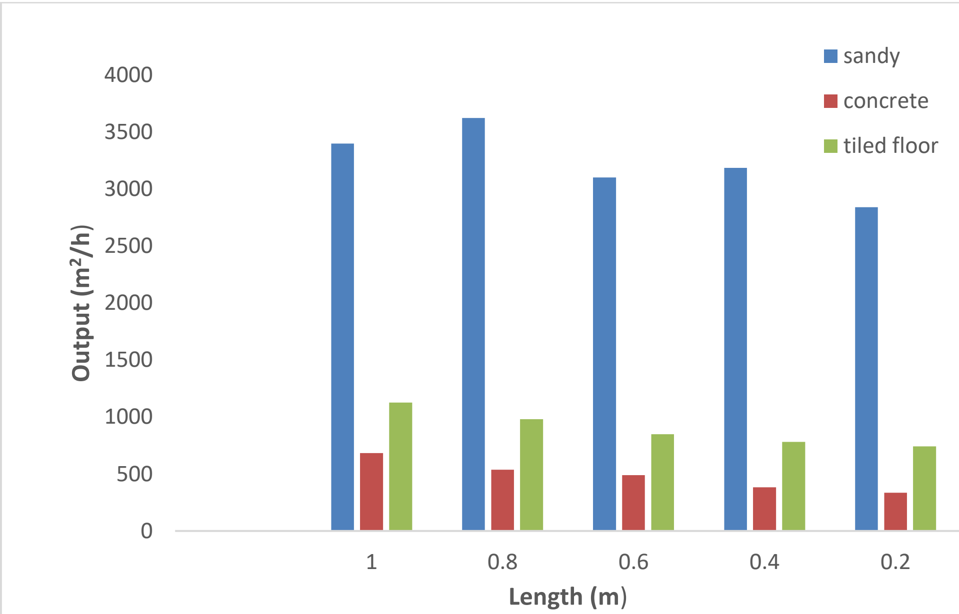

Fig. 4. Swept area output using various broom strand lengths on different floor surfaces

Fig. 4 shows the comparative outputs from sandy, concrete and tiled floors using various oil palm broom lengths. It is observed that the output from sandy surface is very much higher than that of concrete and tiled surfaces. This is because the surface-finish quality requirement for both concrete and tiled surfaces is higher and takes more time and effort to achieve. In sandy surface sweeping, only debris is regarded as dirt. The effects of the sweeping broom spread angle on output data for the various ground surfaces are as shown in Table 6. The broom optimal length of 0.8 m obtained earlier was kept constant while varying the spread angle. From Table 6, it is shown that the highest output on the sandy compound is obtained at 90° spread angle followed by the 75° with 10° giving the lowest. It appears to be that the larger the angle the larger the broom tip contact area with the swept surface which enables a larger area to be swept at a time. However, the trend did not follow consistently as shown on the concrete paved compound where the highest output was obtained at 75° and closely followed by 50° spread angle. It is also observed in the table that for tiled floor the highest output occurred at 50° and followed closely by 75° spread angle. It seems that whereas the larger spread angle of the broom tip influence output positively, there is a limit to which that can happen. On a smoother concrete pavement and tiled floor, the sweeping broom is partially bent such that both the bristle side and tip form the contact surface, thereby increasing the area in contact with the swept surface. Apart from the contact area, the lesser spread angle gives a higher bending stiffness to push through the ground resistance.

Table 6. The Effect of sweeping broom spread angle on output data for the various swept area

Sweeping broom spread angle on output for the swept area of 26.3 m by 7.5 m sandy compound			
Spread Angle (°)	**Time (s)**	**Area (m²)**	**Output (m²/h)**
10	231	197.25	3074
25	227	197.25	3128
50	196	197.25	3622
75	161	197.25	4410
90	127	197.25	5591
Sweeping broom spread angle's output data for the swept area of 13.4 m by 8.6 m concrete paved compound			
Spread Angle (°)	**Time (s)**	**Area (m²)**	**Output (m²/h)**
10	745	115.24	556
25	669	115.24	620
50	544	115.24	762
75	513	115.24	808
90	782	115.24	530
Sweeping broom spread angle output data for swept area of 11.0 m by 2.7 m tiled floor			
Spread Angle (°)	**Time (s)**	**Area (m²)**	**Output (m²/h)**
10	88	29.7	1215
25	87	29.7	1228
50	80	29.7	1336
75	96	29.7	1113
90	101	29.7	1058

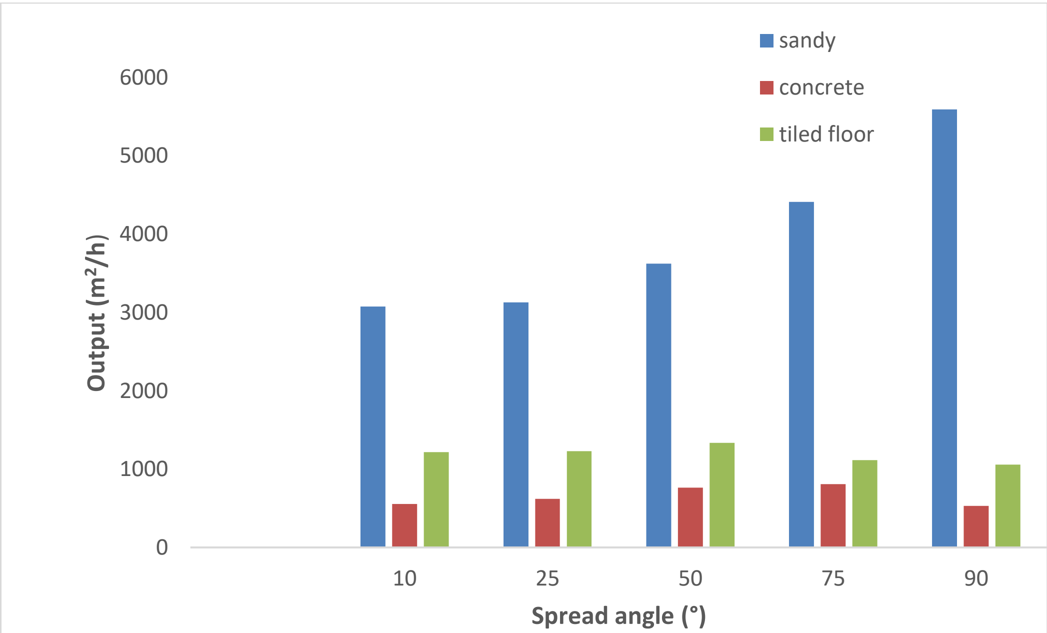

Fig. 5. Swept area output using various broom strand spread angles on different floor surfaces

Fig. 5 shows the comparative swept area output of various floor surfaces using different oil palm strand spread angles. It is found that the output from sandy surfaces is higher than those of concrete and tiled surfaces. It appears to be that the time required to sweep a specific area in sandy surface is less. This is due to the less surface-finish quality requirement. While sand is a dirt on concrete and tiled floor, it is a normal condition on sandy surface. The maximum sweeping outputs for concrete pavement and tiled surface are 808 m^2/h and 1336 m^2/h respectively. Tiled surfaces are smoother and slippery compared to concrete pavements, and hence offers less friction resistance to sweep-off debris and sand dirt. This may be responsible for the higher output observed on tiled surface over concrete. Generally, it was observed that oil palm broom sweeping alone is not sufficient to remove all the fine particles from the concrete and tiled floors. Mopping is required additionally to trap and remove fine and adhesive particles. This collaborates the finding in Amato et al., 2010, which states that vacuum assisted and regenerative air sweepers are better suited to removing finer sediments while mechanical and manual sweepers are better at removing lager debris [21].

4. CONCLUSIONS

Oil palm sweeping broom is a natural eco-friendly sustainable and indispensable cleaning tool for most households and communities due to their unique features. Response analysis from the questionnaire indicates that more than 41% and 63% of the sample size agreed that broom is more rugged and user friendly and thus more durable than the vacuum cleaner and sweeping brushes respectively. Also, more than 72% and 58% agreed that broom is easier to use compared to vacuum cleaner and sweeping brushes respectively. It is found that the broom length and spread angle affects swept area output efficiency, as the broom length decreases, sweeping time increases, when broom gets shorter it becomes more strenuous to use and the shorter sweeping broom, the higher sweeping time that reduce broom output. When the broom is excessively long with a low aspect ratio towards the tip, sweeping time increases because the bristles were too soft to give a firm push on dirt; as the sweeping broom spread angle increases, sweeping time reduces; and for a too widespread angle, sweeping time increases because the bristles become too soft and loses grip on dirt.

From these takeaways, therefore, for an optimal output of the oil palm sweeping broom, an appropriate length of strands with good spread angle are to be used. An efficient design of the form configuration of the oil palm sweeping broom will improve on sweeping output and also lessen the arduous effects of sweeping. This will encourage the use of the oil palm sweeping broom and subsequently support the income earnings of the producers.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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