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The Field Performance of Palm Fibre Insulation Board Treated with Cassava Starch

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Authors' contributions

This work was carried out in collaboration between all authors. Author ME designed the study and supervised the experiments. Authors AOE and OMI wrote the protocol and wrote the first draft of the manuscript and managed literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The field performance of palm fibre insulation board treated with cassava starch solution has been studied. This was done in search of local substitutes for imported insulation materials used in low temperature (45℃ – 200℃) ovens. Fresh oil palm fibr e was collected from palm-kernel, washed with non-reactive detergent to remove its oil content and dried to constant mass in an oven. The dried palm fibre was treated with 0.2 w/w starch solution, compacted into rectangular boards and re-dried in an oven to constant mass. The fibre bands were then installed in a locally developed oven for the field test. The test involved examining the stability of the thermo-physical properties of the insulation board after baking activities for 4 hours. This was done by comparing the density, physical appearance and thermal conductivity of the board before and after the use in the oven for baking. There were no significant changes in the thermo-physical properties observed before and after use. The results indicate that the palm fibre board is suitable for use as an insulation material in low temperature oven application. Successful implementation of the board could contribute greatly to savings on importation costs of conventional insulation materials while enhancing the safer utilization of a by-product of the Nigerian palm oil industry. Furthermore, this will enhance better environmental conditions and comply with the current clamor of converting waste to riches.

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Keywords: Field performance; insulation material; oil palm fibre; cassava starch solution; local substitute; thermo-physical properties; low temperature.

1. INTRODUCTION

There has been an exponential growth of population and material wealth since the industrial revolution. The growth has been associated with the increasing use of energy in devices. Many manufacturing and processing systems produce or utilize heat energy when operating. The efficient use of the insulating property of materials to conserve heat energy depends on the type of material employed which in turn brings in the issue of cost. Hence, it is necessary to effectively plan and design the insulation of such thermal appliances [1,2].

In Nigeria, the growth in population and demand for food has influenced the increasing need for the fabrication of ovens locally for domestic use. The domestic oven commonly used has glass wool as thermal insulation in between its double metal walls. Of recent, there has been the emergence of local fabricators who rely mainly on imported wool glass for the insulation of the ovens resulting in an increase in the cost of the products. Therefore, developing insulation materials locally that could replace the imported ones will help to reduce the cost of equipment that uses them. Before introducing the local insulation material into the market as a substitute, the field performance tests must be carried out [3-6].

There are lot materials that are readily locally available especially as by-product of agricultural processes. These materials can be processed to provide good substitutes for imported insulation materials. Furthermore, this could contribute to environmental sanitation while generating a mean of earning some income [7,8]. However, no naturally occurring biomass is suitable for use as an insulation material directly. It must therefore undergo some forms of treatment to improve its properties for usage and subsequent manufacturing or forming processes if required [9–11]. Naturally occurring oil palm fibres is a common example. Some forms of treatments are necessary to ensure the stability of the biomass such as reduction of moisture content of the oil palm fibre, removal of residual oil palm and addition of suitable additives such as starch to enhance its usage [12–15].

Agro-fibres have been used as thermal insulation especially in the building sectors in many countries [7,16]. Coffee husk and hulls [17], wood [18], waste tea leaves [19,20], coconut husk [21,22], bagasse [23], cotton [24] and oil palm [25] have all been used for particle board production in many regions of the world. In this way they not only provide a renewable material source and low thermal conductivity, but also generate a non-food source of economic development for farming and rural areas. Studies have been conducted using palm oil fibres for thermal insulation material in thermal processes especially at low temperatures [26–29].

Insulation board production from these materials is feasible for a number of reasons. Cellulose accounts for 47.6% of the oil palm frond [30] and for 62.9% of the empty fruit bunch content [31-33]. Cellulose has a potential to be used in the paper and fiber-board manufacturing. Large amounts of oil palm wastes will continually be generated as long as palm oil products are being produced. These wastes are biodegradable and therefore more environmentally benign compared to many of the synthetic materials being used [34,35].

Therefore, this study concentrates on applying the results of the previous tests in a simple locally fabricated conductivity testing device at steady state conditions. This is all in the process of finding an alternative resource from locally available agricultural residues such as palm oil fibre to produce thermal insulation construction materials in board form. This will not only reduce the operation cost but also help to preserve the environment. The binder used is the waste starch solution from several cassava processing systems which is of great interest from an environmental perspective [15]. Evaluation mainly included production methods and thermal conductivity measurements.

The objective of this research is to determine the preliminary field performance of oil palm fibre insulation boards treated with cassava starch solution in a locally fabricated oven. The specific aims include sourcing for an alternative local material for application in locally fabricated ovens, enhancement of local development of ovens using the insulation material and consequently minimizing the cost of ovens. Furthermore, this study could provide the basis for the development of a suitable technology for mass production of the insulation materials. The field performance results will be of great benefit to small scale industries that are into the construction of oven and enable the minimizing of heat loss in various heat related applications with a locally constituted insulation material.

2. MATERIALS AND METHODS

The materials used for this work included oil palm fibre and cassava starch solution (CSS). The equipment and materials used to produce the sample included a 35 x 50 x 4 cm of aluminium mould, compressive weights of 34 and 30 kg, a Gallenkamp hotbox oven, 5000 ml and 250 ml of beakers, a kerosene stove, a Harvard trip balance, a sliding balance, distilled water and detergent. The equipment and materials used to fabricate the oven included 2 mm metal sheet, 1 in. angle iron, a block wood of dimension 1 x 1 x 1 inch, fasteners, roller, cold weld adhesive, a 2000 Watts electric cooking plate fitted with thermal sensor and thermostat, a dual channel thermocouple thermometer manufactured by Einstruments, K type thermocouple with L bend surface probes and a 2500 VA variable voltage regulator.

The assessment of the insulation material involved

i. The effect of temperature on the thermal conductivity of the oil palm fibre under actual use condition.
ii. The effect of temperature on the physical structure of the fibre board under actual use condition.

Extracted palm kernel fibre was washed using water and a non-reactive detergent to completely remove the oil content of the fibre. The fibre was initially sun dried to reduce its moisture content. Further drying was carried out using Gallenkamp hotbox oven to completely remove the moisture content at a constant weight of the fibre. The dried fibre was properly shredded so as to increase its surface area to enable proper mixture with starch solution.

Fig. 1 shows the flow diagram of the process for extraction of starch from fresh cassava roots. The screened starch was later sun dried to completely remove its moisture content. The dried starch was grounded so as to increase its surface area and further screening was carried out using 425 µm diameter screens.

To prepare the insulation board samples, 850 g of the dried palm fibre was gradually soaked in a cassava starch solution initially prepared by mixing 1000 ml of distilled water at 100℃ with 170 g of cassava starch powder at 0.2 starch-fibre concentration and stirred until there was a proper mixture. The mixture was poured into an aluminium mould of dimensions 35 x 50 x 4 cm and compressed with a weight of 24 kg to a thickness of 3 cm. The compressed sample was dried in a Gallenkamp hotbox oven at a constant temperature of 80℃ until a constant weight was obtained. The procedure was repeated to obtain the other three samples of equal dimensions. The procedure was further repeated using 750 g of the dried oil palm fibre, 150 g of cassava starch, and a mould of dimension 35 x 30 x 4 cm and compressive weight of 20 kg for two consecutive times so as to produce two samples of equal dimension making a total number of six samples.

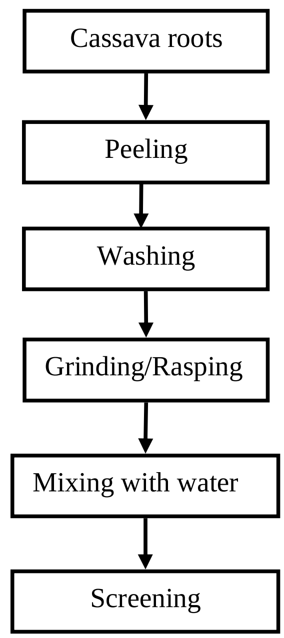


Fig. 1. Flow diagram of the extraction of cassava starch

The test oven comprises mainly of rectangular inner and outer walls made of 2 mm mild steel, 1 inch mahogany block wood fastened to angle iron and electric cooking plate. The electric cooking plate was installed at the base of the test oven and fixed firmly with fasteners. A thermal sensor and a thermostat were connected to the heating element of the electric cooking plate to ensure steady state energy supply in the test oven. Electricity supply to the electric cooking plate was taken from public source but passed through the automatic voltage regulator to ensure steady energy supply to the electric cooking plate element. Between the inner and outer walls is 3 cm thick sample of the insulation board to resist the heat transfer from the inner to the outer wall. Two holes were drilled on the top of the test oven for the passage of the thermocouple probes. The dual channel thermocouple thermometer was used to read the temperature of the inner and outer walls of the test oven. Fig. 2 shows samples of the insulation boards while Fig. 3 shows the inside view of the test oven.

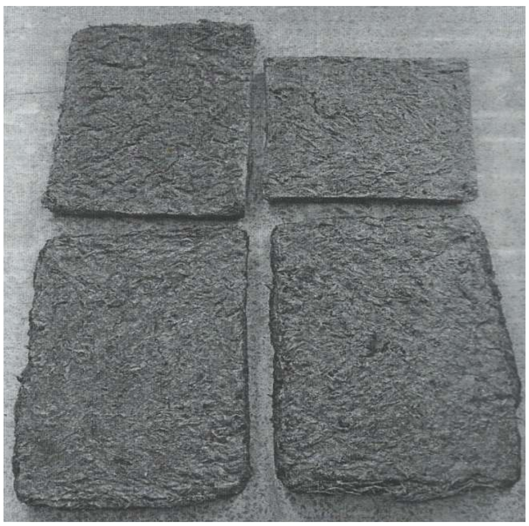


Fig. 2. Samples of the insulation boards

The oven was preheated to a temperature of 220℃ in 25 minutes before inserting the already prepared dough into the oven. The temperature was reduced to a constant baking temperature of 180℃ with the aid of the thermostat. The dough was allowed to bake for 20 minutes. The temperature of preheating, baking, inner and outer walls of the oven were noted and recorded. After using the test oven to bake several loaves of bread for a period of four hours, the insulation material was detached and observed.

In determining the thermal conductivity (k) of the treated insulation material, the absolute steady-state measurement was used because baking in ovens is normally done under such conditions. The parameters of the test materials noted were the thickness and cross-sectional area. The inner wall surface was heated up by an electric power source which was kept constant. The heat from the inner wall was conducted through the insulation material to the outer wall of the oven. The temperature of the inner and outer wall surface T_1 and T_2 respectively were measured by means of thermocouple. As heat transfer becomes steady in which state T_1 and T_2 remain invariable with time, the quantity of heat transfer (Q) through the metal sheet and the insulation material is same. The quantity of heat transfer was calculated using equation 1.

$$Q_p = \frac{k_p A(\Delta T)}{x_p} \tag{1}$$

Where k_p = thermal conductivity of the mild steel, A = surface area of the metal sheet, ΔT = temperature difference between the surfaces of the inner wall and x_p = thickness of the metal sheet. Similarly, the thermal conductivity of the insulation material was calculated using equation 2.

$$K_S = \frac{Q_S X_S}{A(T_1 - T_2)} \tag{2}$$

Where Q_S - quantity of heat transferred, X_S = thickness of the insulation material, A = surface area of the insulation board, T_1 = temperature of the inner wall, T_2 = temperature outside the wall (ambient) and K_S = thermal conductivity of the insulation material.

The density of the oil palm fibre board was determined by weighing directly a cross-section of the insulation board on top loading balance weighing machine that has an accuracy of 0.001g to obtain the mass (m). The area (A) and thickness (X) were measured with the aid of a metre rule to compute for the volume of the oil palm fibre board. The density of the palm fibre board was calculated using equation 3.

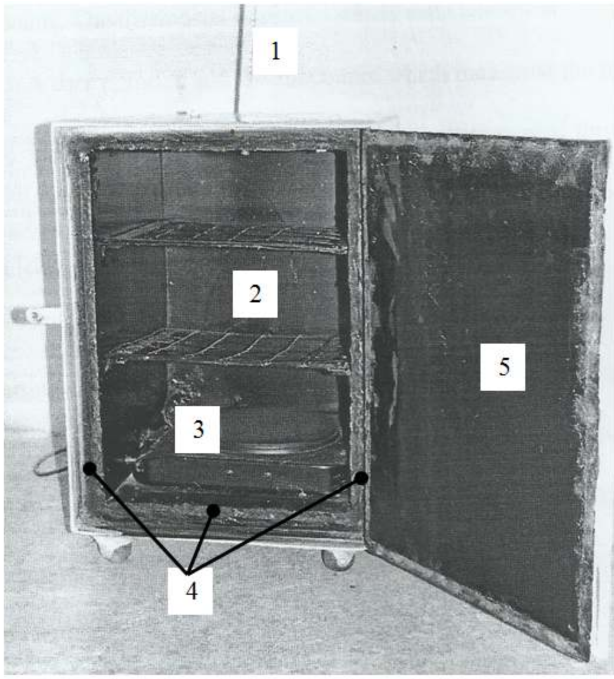
$$\rho = \frac{m}{v} \tag{3}$$

Where ρ - density of the oil palm fibre board (kg/m^3), m - mass of the oil palm fibre board (kg) and v - volume of the oil palm fibre board (m^3).

The pressure exerted on the treated oil palm fibre insulation material during compression in the mould was determined using equation 4.

$$P = \frac{F}{A} \tag{4}$$

Where P = pressure (N/m^2), F = force acting perpendicularly (N) and A = area of the surface (m^2).



1. Temperature probe
2. Interior of test oven
3. Hot plate
4. Insulation boards
5. Test oven door

Fig. 3. Inside view of the test oven

3. RESULTS AND DISCUSSION

The data obtained from the various experimental tests carried out on the treated palm fibre insulation material (0.2 w/w cassava starch) in the course of the study are presented in tables below. Results of the compaction test are shown in Table 1. The result shows a 25% reduction in the thickness of the samples. Compaction was necessary to minimize the presence of air pockets within the fibers of the test insulation material which would interfere with results of thermal conductivity of the samples. This is because the thermal conductivity of air is significantly different from that of the test insulation material.

The density of the oil palm fibre treated with cassava starch insulation board before and after the performance test is shown in Table 2. The result shows a slight reduction of density of the insulation board after use due to reduction of the mass of the board. The change in mass may have been contributed by a slight consumption of the binder by the excessive heat and possible wear of the board during installation into and removal from the test oven. However, the dimensions of the board remained unchanged after use suggesting structural stability of the samples which will be invaluable in practical use of the insulation boards in oven design. Also, there was a slight change in colour from light to slightly darker brown; and the physical structure of the insulation board samples after use because the material was subjected to very high temperature of 320°C during the calibration of an alcohol in glass thermometer using the dual channel thermocouple thermometer as reference. The standard applied is ANSI/NCSL Z540-1-1994 and the accuracy of the instrument is $\pm 0.5\, FSD$ with a resolution of 0.01°C. The temperature of 320^{o}C is outside the temperature range intended for the application of the test insulation material investigated in this work at its present stage. However, it strengthens the existence of the possibility of further development of the material to withstand more adverse conditions without losing structural stability and texture. This forms the basis for further work in order to improve the functional characteristics of the oil palm fibre insulation board in terms of higher temperature applications than the range for this study.

Table 3 shows the temperatures attained by the test oven and the surroundings during baking of the bread while Table 4 shows the mean computed thermal conductivity and the parameters used. The results show that the mean thermal conductivity of the oil palm fibre board with 0.2 w/w cassava starch and at 161.1°C was found to be 0.29 W/m K. With the

Table 1. Compaction of the palm fibre samples

Force (N)	Initial thickness (m)	Final thickness (m)	Reduction in thickness (%)	Applied pressure (kN/m^2)
240	0.04	0.03	25	1.37

Table 2. Density of the oil palm fibreboards before and after use

Period	Mass of dry board (kg)	Volume of board (m^3)	Density (kg/m^3)
Before use	0.85	0.00525	161.9
After use	0.83	0.00525	158.1

Table 3. Temperatures attained during baking process

	1st (°C)	2nd (°C)	3rd (°C)	Average (°C)
Inner wall (T_{in})	162.1	160.6	161.1	161.3
Outer wall (T_{out})	64.1	62.1	60.6	62.3
Ambient (T_{amb})	26.2	29.2	30.0	28.5

Table 4. Mean computed thermal conductivity of oil palm fibreboard

Material	Thickness X (mm)	Change on temperature (ΔT)	Sectional area A (m^2)	Quantity of heat (kJ)	Thermal conductivity k (W/m K)
Palm fibre	0.03	372	0.175	623.35	0.29

low thermal conductivity of the palm-kernel fibre and from the result of low thermal diffusivity of 2.129×10^{-7} m^2/s and high specific heat value of 27095.23 J/kg℃ obtained from an earlier unpublished study, the material has the potentials of a good heat insulating material for use in the construction of low temperature ovens and furnaces, and other low temperature thermal processes.

The value of the thermal conductivity of the insulation board in its present state though promising is higher than those of several conventional insulation materials. However, the main objective now is to convert waste biomass materials into useful insulation material while contributing to waste management and enhancing environmental conditions. The handling of oil palm fibre by the many small and medium enterprises spread across many rural areas in Nigeria can be updated and upgraded into insulation board making. This will also contribute to employment of the theming youths especially with the new administration's commitment to reduce unemployment significantly.

4. CONCLUSION AND RECOMMENDATIONS

The field performance of palm fibre insulation board treated with cassava starch has been studied and it was observed that

1. The oil palm fibre treated with cassava starch solution has low thermal conductivity.
2. It can be used in the production of low temperature ovens and the likes with a range of temperature (45℃ – 200℃) used mainly for domestic cooking.
3. It has the capacity to serve as a substitute for imported insulation materials in the future.
4. The material is also available to support the local industry which will in turn create job opportunities, increase the nation's foreign earnings and also bring about scientific development.
5. It will contribute to waste handling of the local palm oil industries.

Further work will be undertaken to improve on the thermal conductivity, the physical structure and tensile and compressive strengths of the material. Particularly, addition of other biomass such as coconut fibre and small quantities of other additives will be tested. Test conditions will be improved in order to increase the range of the maximum temperature of use and emission data will then have to be studied.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Ikenweiwe NB, Bolaji BO, Bolaji GA. Fabrication and performance assessment of a locally developed fish smoking kiln. Ozean Journal of Applied Sciences. 2013; 3(4):363-369.
2. Okafor BE. Simple design of a dual-powered domestic oven. International Journal of Engineering and Technology. 2014;4(5):313-317.
3. Bello SR, Odey SO. Development of hot water solar oven for low temperature thermal processes. Leonardo Electronic Journal of Practices and Technologies. 2009;14:73-84.
4. Kulla DM, Ebekpa IM, Sumaila M. Design and construction of a small scale charcoal baking oven. International Journal of Recent Development in Engineering and Technology. 2014;2(6):89-94.
5. Yusuf SO, Garba MM, Momoh M, Akpootu DO. Performance evaluation of a box-type solar oven with reflector. International Journal of Engineering and Science (IJES). 2014;3(9):20-25.
6. Yusuf SO, Garba MM, Momoh M, Akpootu DO. Performance evaluation of a box-type solar oven with reflector. International Journal of Engineering and Science (IJES). 2014;3(9):20-25.
7. Zhou X, Zheng PZ, Li H, Lu C. An Environmentally-friendly thermal insulation material from cotton stalk fibers. Energy and Building. 2010;42:1070-1074.
8. Sihabut T, Laemsak N. Feasibility of producing insulation boards from oil palm fronds and empty Fruit bunches. Songklanakarin J. Sci. Technol. 2010; 32(1):63-69.
9. Manohar K, Ramlakhan D, Kochhar GS, Haldar S. Biodegradable fibrous thermal insulation. Journal of the Brazilian Society of Mechanical Sciences and Engineering. 2006;28(1):53-55.
10. Manohar K. Renewable building thermal insulation – oil palm fibre. International Journal of Engineering and Technology. 2012a;2(3):475-479.
11. Mohd Yuhazri YY, Sihombing H, Jeefferie AR, Ahmad MAZ, Balamurugan AG, Norazman MN, Shohaimi A. Optimization of coconut fibers toward heat insulator applications. Global Engineers & Technologist Review. 2011;1(1):35-40.
12. Panyakaew S, Fotios S. Agricultural waste materials as thermal insulation for dwellings in Thailand. Preliminary results, PLEA 2008–25th Conference on Passive and Low Energy Architecture, Dublin; 2008.
13. Mohapatra RC, Mishra A, Choudhury BB. Investigations on thermal conductivity of palm fibre reinforced polyester composites. IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE). 2014;11(1): 48-52.
14. Mounika M, Ramaniah K, Ratnaprasad AV, Rao KM, Reddy KHC. Thermal conductivity characterization of bamboo fibre reinforced polyester composites. J. Mater. Environ. Sci. 2012;3(6):1109-1116.
15. Bekalo SA, Reinhardt HW. Fibers of coffee husk and hulls for the production of particle board. Mater. Struct. 2010;43:1049-1960.
16. Kawasaki T, Kawai S. Thermal insulation properties of woodbased sandwich panel for use as structural insulated walls and floors. J. Wood. Sci. 2006;52:75-83.
17. Shi JS, Li JZ, Fan YM, Ma HX. Preparation and properties of waste tea leaves particleboard. For. Stud. China. 2006;8:41-45.
18. Abdul Khalil HPS, Hanida S, Kang CW, Nik Fuaad NA. Agrohybrid composite: The effects on mechanical and physical properties of oil palm fiber (EFB)/glass hybrid reinforced polyester composites. Reinf. Plast. Compos. 2007;26:203-218.
19. Alma MH, Bektas I, Tutus A. Properties of cotton carpel-based particleboards. Ind. Crop. Prod. 2005;22:141-149.
20. Viswanathan R, Gothandapani L, Kailappan R. Water absorption and swelling characteristics of coir pith particle board. Bioresour. Technol. 2000;71:93-94.
21. Viswanathan R, Gothandapani L, Kailappan R. Production process for high density high performance binderless boards from whole coconut husk. Ind. Crop. Prod. 2004;20:97-101.
22. Widyorini R, Xu J, Umemura K, Kawai S. Manufacture and properties of binderless particleboard from bagasse. I. Effects of raw material type, storage methods, and manufacturing process. J. Wood. Sci. 2005;51:648-654.
23. Yalinkilic MK, Imamuraa Y, Takahashi M. Biological, physical and mechanical properties of particleboard manufactured from waste tea leaves. Int. Biodeter. Biodegr. 1998;41:75-84.
24. Tangjuank S. Thermal insulation and physical properties of particle boards from

pineapple leaves. International Journal of Physical Sciences. 2011;6(19):4528-4532.

25. Soom RM, Hassan WHW, Top AGM, Hassan K. Thermal properties of palm fibre cellulose and its derivatives. Journal of Oil Palm Research. 2006;18:272-277.
26. Suradi SS, Yunus RM, Beg MDH, Rivai M, Yusof ZAM. Oil palm bio-fiber reinforced thermoplastic composites-effects of matrix modification on mechanical and thermal properties. Journal of Applied Science. 2010;10:3271-3276.
27. United Nations Environmental Programme, UNEP. Converting waste agricultural biomass into a resource: Compendium of technologies. Division of Technology, Industry and Economics, International Environmental Technology Centre Osaka/Shiga, Japan. 2009;6-8.
28. Hassan S, Al-Kayiem HH, Ghaffari A. development of thermal insulation from oil palm fiber for chimney of fire tube steam packaged boiler. Applied Mechanics and Materials. 2014;666:31-35.
29. Manohar K. Experimental investigation of building thermal insulation from agricultural by-products. British Journal of Applied Science & Technology. 2012b;2(3).
30. Ibrahim SH, Sia WK, Baharun A, Nawi MNM, Affandi R. Thermal performance of oil palm fibre and paper pulp as the insulation materials. UNIMAS e-Journal of Civil Engineering. 2014;22-28.
31. Wanrosli WD, Zainuddin Z, Law KN, Asro R. Pulp from oil palm fronds by chemical processes. Industrial Crops and Products. 2007;25:89-94.
32. Hudzari RM, Sapuan SM, Syazili R, Azhar AWM. Optical properties analysis for crop maturity index. Journal of Food, Agriculture & Environment. 2013;11(2):571-575.
33. Wan Ishak Wan Ismail, Lam Wai Yip, Mohd Hudzari Haji Razali. Determination of the optimum frequency for *Elaeis guineensis Jacq*. detachment, African Journal of Agriculture Research. 2011; 6(25):5656-5663.
34. Law KN, Daud WRW, Ghazali A. Oil palm empty-fruit-bunch (OPEFB). Bioresources. 2007;2:351-362.
35. Wang J, Hayakawa K. Thermal conductivity of starch gels at high temperature influenced by moisture. Journal of Food Science. 1993;58(4):884-887.

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