Production of Ceiling Board from *Piliostigma thonningii* using Styrofoam Adhesive as Binder

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Abstract. The use of synthetic fibres resulted in environmental degradation and the growing interests towards the utilisation of readily available agricultural fibres as a potential replacement for synthetic fibres. This research aims to produce a ceiling board composite from *piliostigma thonningii* particulate using styrofoam adhesive binder. The board was produced from the readily available materials leading to the low cost of production. The composition has a formulation of fibre/binder mixing ratios (2:1, 1:1, 1:2 w:w), pressures of (100, 300, 500 kg/m^2) and temperatures of (30, 65, 100 °C) respectively. The process was successfully modelled and optimized using a Box–Behnken design method. The optimal conditions for the *piliostigma thonningii* board were found to be fibre/binder mixing ratio of 1:1 w:w, pressure of 500 kg/m^2 and temperature of 92 °C yielded response values of density (151.5 kg/m^3), water absorption (9.04 %), tensile strength (16.9 N/m^2), thermal conductivity (0.11 W/mK). Hence the board has greater insulating properties and good potential to be used as a ceiling board.

Keywords: production; *piliostigma thonningii*; ceiling board.

INTRODUCTION

Composite is a combination of two materials in which one of the material, called the reinforcing phase is embedded in the other material called the matrix phase [17].

Ceiling board is composite products manufactured from particles of wood or other cellulosic fibre materials using adhesive as a binder.

The important role of ceiling board:
– creates a perfect ambience that can improve the acoustical system;
– use as insulators and reduces heat transfer into the building;
– adds value to the existing architecture of buildings;
– use in holding up building materials.

The rising concern towards the environmental issues on the one hand and the need for more versatile polymer-based materials, on the other hand, have led to increasing interest in polymers filled with natural lignocellulosic agro fibre. The Lignocellulosic fibres are low-cost raw material, abundant in nature and renewable. Besides that, the less abrasive nature of the lignocellulosic fibres offered a friendlier processing environment and offered good thermal and insulating properties, easily recyclable and biodegradable especially when used as reinforcement in a biopolymer.

Natural reinforcements have advantages over reinforcements as a result of the natural alignment of carbon-carbon bonds and also significant strength, stiffness [12], low density, low cost and bio-degradability they offer.

Piliostigma thonningii is a woody plant found grows in savannah regions that are moist and wooded grass land in low to medium altitudes; it is widely distributed in Africa [10]. The English name is monkey bread or camel's foot. In Nigeria, the plant grows abundantly as a wild, uncultivated tree.

Piliostigma thonningii is a plant which contents 85 % lignocellulosic fibre as shown in Table 1; the lignocellulosic fibres have the potential to be an effective reinforcement in thermoplastics and thermosetting materials [5].

Table 1 – The basic chemical component and compositions of lignocellulosic fibres in *Piliostigma thonningii* plant

Component Value	Percentage (%) composition
Moisture	6.71
Ash	3.50
Protein	3.37
Cellulosic Fibres Cellulose Hemi – Cellulose lignin	 40 lignocellulose 25 lignocellulose 20 lignocellulose
Lipid	1.42
Acid value	13.73±1.40
Iodine vale	50.76 ±1.80
Colour	Pinkish to dark brown

Source: [10]

The styrofoam is an environmental unfriendly solid waste styrene; non-biodegradable materials and readily soluble in acetone but insoluble in water [1]. However, it is a very lightweight, plastic material, formed when air (or other "blowing agents") blown through molten polystyrene as it is extruded to foam up and produces the light foamy material known as "Styrofoam".

Styrofoams are normally thrown away after been used during ceremonies, occasions or after other materials been packaged were removed.

This paper aims at the production, optimisation and evaluation of the fundamental properties of ceiling board composite from *piliostigma thonningii* that can have a potential application of low thermal conductivity and also help to preserve the environment by reducing the indiscriminate littering of Styrofoam.

MATERIALS AND METHODS

Materials. The major raw materials for this work are the stem fibres of *piliostigma thonningii.* Other materials include styrofoam, unsaturated polyester resin, sodium hydroxide (NaOH), gasoline, distilled water.

Preparation of styrofoam adhesive. The styrofoam was cleaned and made free of dirt. Forty grams (40 g) of styrofoam was dissolved in 120 ml of gasoline and stirred to enhance the dissolution of the styrofoam. In this research, the 60 % unsaturated polyester resin was mixed with 40 % dissolved styrofoam adhesive. The formulated solution was stirred twice daily for a week until the formulated adhesive reaches homogeneity and stabilisation.

Preparation Piliostigma thonningii into wood particles. The *piliostigma thonningii* stems were collected and washed thoroughly with clean water to remove any unwanted particles. The cleaned *piliostigma thonningii* (stem) were reduced into chips, then mercerised using 5 % w/v sodium hydroxide (NaOH) solution at room temperature for 24 hours. The *piliostigma thonningii* (chips) were thoroughly washed in fresh tap water and air dried. The dried chips were ground into small particle sizes. The sieve analysis of particles was carried out by BS 1377-3:2018 [6].

Sample Preparation. Three numbers of moulds of 0.15 m by 0.15 m were constructed with a thickness of 0.10 m. The required quantity of *piliostigma thonningii* particle sizes was mixed with prepared styrofoam adhesive ratios and compounded into the mould. Pressure and heat were applied for crosslinking and hardening the boards. The board's sample was cut and prepared for characterisation tests subjected to Density, Water absorption, Tensile strength and Thermal conductivity.

Experimental Design. Equation 1 was used in determining the number of experimental runs for the design.

$$N = k^2 + k + Cp \tag{1}$$

where k is the number of factors, Cp is the number of replication.

Minitab 17 software Design Expert was used, and the process was successfully modelled and optimised using a Box-Behnken design method.

The composition has a formulation of fibre/binder mixing ratios (2:1, 1:1, 1:2 w:w), pressures of (100, 300, 500 kg/m^2) and temperatures of (30 °C, 65 °C, 100 °C) respectively.

The Analysis of variance (ANOVA) was also used to check the adequacy of the model for the experimental outputs (responses) at nearly all conditions.

Determination of density. The densities of the boards were determined by the ASTM C303-10(2016)e1 (Standard Test Method for Dimensions and Density of Preformed Block and Board–Type Thermal Insulation) [3]. From each of the boards prepared, three (3) sample specimens were cut for the test, and the volume of each specimen was calculated using equation as follows:

$$Volume, \mathrm{m}^3 = l \times w \times \Delta x \quad (2)$$

The mass of each specimen was determined using a digital weighing balance and the mass recorded. The density of each specimen is determined using equation (2) based on ASTM (3):

$$\text{Density}, \frac{kg}{m^3} = \frac{weight\ of\ the\ composite}{volume\ of\ the\ composite} \quad (3)$$

Determination of water absorption. The water absorption test was conducted according to ASTM D1037-12 [2]. The specimens have a dimension of 0.14 m × 0.14 m × 0.1 m used in the determination of the density were used since their masses and volume were recorded. Each specimen was immersed in water at ambient temperature of 24 hours until equilibrium. The specimens were removed and patted dry with a towel (lint free) and then weighed using a digital weighing balance. The dry weight before immersion (w_1) and the weight after immersion (w_2) were noted. The water absorption was expressed as the percentage increase in volume based on the volume before immersion. Equation (4) was applied to determine the percentage of water absorption by ASTM D570-98(2018) [4]:

$$W_A = \frac{w_2 - w_1}{w_1} \times 100 \quad (4)$$

where w_1 is the weight of the sample before immersion in water; w_2 the weight of the sample after immersion in water.

Determination of tensile strength. Monsanto Tensometer machine is used to determine the tensile strength of the ceiling board composites of various compositions as specified by the American society for testing and material. The sample dimensions of 60 × 8 × 5 mm with dumb bell shape outside the gauge length. The dumb bell part clamped to jaws of the machine and the extension produces within the gauge span of the specimen. The evaluation of ulthe timate tensile strength (UTS) can be determined using equation (5).

$$\text{UTS} = \frac{Average\ force}{cross\ section\ area} \quad (5)$$

Determination of thermal conductivity. The thermal conductivity of the boards was determined by [2]. The equipment used for the test was Armfield HT10XC Heat Transfer Service Unit and HT11C Computer Compatible Linear Heat Conduction Accessory. From each of the boards, four (4) specimens were cut in the form of a disc of diameter (d) 25 × 1 mm and the thickness (x) was measured and recorded. A specimen was clamped tightly in between two faces of heated and cooled brass sections, the heater voltage (V) was set to 10 volts, and the heater current (1) was read from the console and recorded. After HT11C was stabilized, the temperatures T_1, T_2, T_3, T_7, and T_8 were also read and recorded from the console display. Where T_1, T_2 and T_8 are the thermocouples connected to the heating section of the instrument and T_6, T_7 and T_8 are those connected to the cold section of the instrument. The thermal conductivity (k) of a material was determined from equation (6)–(8):

$$k = \frac{Heat \times Distance}{Area \times Temperaturegradient}. \quad (6)$$

$$\Delta T = T_{hot} - T_{cold}, \quad (7)$$

where $T_{hot} = T_2 - \frac{(T_2 - T_3)}{2}$, $T_{cold} = T_6 - \frac{(T_6 - T_7)}{2}$.

Apply Fourier rate equation to determine the thermal conductivity (k) of a specimen (8):

$$Q = -kA\frac{\Delta T}{\Delta x}\left(\frac{\mathrm{W}}{\mathrm{mK}}\right). \quad (8)$$

RESULTS AND DISCUSSION

Various experiments were determined; the results of the experiment obtained were subjected to Response Surface Regression analysis using the Statistical package Minitab 17. The independent variables are *piliostigma thonningii* fibre / styrofoam adhesive ratio, pressure, and temperature. The density, water absorption, tensile strength and thermal conductivity test results measured as output parameters (responses) for the 15 runs are given in Table 2.

Table 2 – The independent variables and responses

Run	*Piliostigma thonningii* / Styrofoam Adhesive (w:w)	Pressure (kg/m^2)	Temperature (°C)	Density (kg/m^3)	Water Absorption (%)	Tensile strength (N/m^2)	Thermal conductivity (W/mK)
1	1:2	100	65	202.47	0.83	15.94	0.25
2	2:1	100	65	152.35	28.63	10.34	0.10
3	1:2	500	65	201.99	0.68	14.20	0.23
4	2:1	500	65	145.85	25.21	19.32	0.06
5	1:2	300	30	218.25	0.78	13.84	0.23
6	2:1	300	30	140.31	27.30	9.81	0.12
7	1:2	300	100	185.43	4.26	15.02	0.26
8	2:1	300	100	133.78	15.88	12.02	0.06
9	1:1	100	30	161.67	15.67	13.82	0.14
10	1:1	500	30	158.34	13.74	12.58	0.12
11	1:1	100	30	149.72	15.54	14.50	0.09
12	1:1	500	65	149.22	10.55	17.82	0.08
13	1:1	300	65	130.79	10.95	10.87	0.08
14	1:1	300	65	131.26	10.95	10.85	0.08
15	1:1	300	65	130.99	10.95	10.89	0.08

The analysis of variance (ANOVA) technique was used to check the adequacy of the developed models at 95 % confidence level for the model to satisfy the adequacy conditions in non-linear form.

Table 3 shows the ANOVA results for density, where the model is significant at 1% level with a p-value of 0.000. The main terms: w:w and temperature are both significant at 1 % level with p-values of 0.000 and 0.006 respectively while only pressure is not significant. The Square terms indicated that all the three independent variables are significant at 1% level. While only interaction between w:w and pressure are significant at 5 % level with a p-value of 0.039. The R-squared value for the model is 99.05 % which shows that the R-squared is enough, explained adequately for the model to be considered.

Table 3 – ANOVA result for model representing density

Source	DF	Adj SS	Adj MS	F-value	P-value
Model	9	11574.2	1286.02	57.84	0.000
Linear	**3**	**7424.5**	**2474.84**	**111.31**	**0.000**
w:w	1	6953.5	6953.54	312.75	0.000
Pressure	1	14.6	14.62	0.66	0.454
Temperature	1	456.4	456.37	20.53	0.006
Square	**3**	**3965.9**	**1321.96**	**59.46**	**0.000**
w:w *w:w	1	3252.2	3252.18	146.27	0.000
Pressure *Pressure	1	827.93	827.93	37.24	0.002
Temperature *Temperature	1	282.70	20.17	12.72	0.016
2-way interaction	**3**	**183.8**	**61.27**	**2.76**	**0.152**
w:w *Pressure	1	9.0	9.04	0.41	0.552
w:w *Temperature	1	172.8	172.76	7.77	0.039
Pressure*Temperature	1	2.00	2.00	0.09	0.776
Residual	5	111.2	22.23		
Lack of fit	**3**	**111.2**	**37.02**	**638.85**	**0.002**
Pure error	**2**	**0.00**	**0.00**		
Total	14	11685.4			

Model summary

S	R-sq, %	R-sq(adj), %	R-sq(pred), %
4.71525	99.05	97.34	84.79

Water Absorption. The results in Table 4 shows that the model is significant at 1 % level with a p-value of 0.002. The lack of fits test shows significance at 1 % level, which suggests that higher order terms can still be incorporated into the model. The Main terms show that w:w is significant with a p-value of 0.000, while pressure and temperature are not significant.

Table 4 – ANOVA result for water absorption

Source	DF	Adj SS	Adj MS	F-value	P-value
Model	9	1134.59	1350.8	21.60	0.002
Linear	**3**	**1052.67**	**26.07**	**60.11**	**0.000**
w:w	1	1023.07	1023.0	175.25	0.000
Pressure	1	13.75	13.75	2.36	0.185
Temperature	1	15.85	15.85	2.71	0.160
Square	**3**	**21.42**	**7.14**	**1.22**	**0.393**
w:w *w:w	1	1.05	1.05	0.18	0.690
Pressure *Pressure	1	20.47	20.47	3.51	0.120
Temperature *Temperature	1	1.20	1.20	0.21	0.669
2-way interaction	**3**	**60.50**	**20.17**	**3.45**	**0.108**
w:w*Pressure	1	2.68	2.68	0.46	0.528
w:w *Temperature	1	55.48	55.48	9.50	0.027
Pressure *Temperature	1	2.34	2.34	0.40	0.554
Residual	5	29.19	5.84		
Lack of fit	**3**	**29.19**	**9.73**	**345053**	**0.000**
Pure error	**2**	**0.00**	**0.00**		
Total	14	1163.78			

Model summary

S	R-sq, %	R-sq(adj), %	R-sq(pred), %
2.41614	97.49	92.98	59.87

For the Square terms show that all the square factors for the three variables are not significant at 5 % level. In the interactions, it is only the interactions between w:w and temperature that shows significance at 5 % level with a p-value of 0.027. The other interactions are not significant. The R-squared value of the model is 97.49 %; this implies that R-squared is enough, which explained adequately for the model to be considered

Tensile strength. Table 5; shows the ANOVA result for Tensile strength. The result shows that the model is significant at 5% level with a p-value of 0.037. This is enough even though the lack of fit suggests the addition of higher-order variables (i.e. significant at 1%). The variables in the main model terms show that: Pressure and Temperature are relatively significant at 10 % with p-values of 0.073 and 0.065 respectively, while w:w is not significant. The square terms indicated only pressure is significant at 1 % per cent level with a p-value of 0.008, while others are not significant. The interaction between w:w and pressure are significant at 5 % level with a p-value of 0.014. The other interactions are not significant. The R-squared value for the model is 90.87%, which reveals that the independent variables account for 90.87% of the variation in tensile strength.

Thermal Conductivity. The results in Table 6 shows that the model is significant at 1% level with a p-value of 0.000. The lack of fits test shows significance at 1% level, which suggests that higher order terms can still be incorporated into the model and the main term: w:w is significant with a p-value of 0.000, while pressure is relatively significant at 10 % level with a p-value of 0.069 and temperature is significant at 5 % level with a p-value of 0.017 while the square term show that; w:w *w:w is significant at 1 % level, temperature is significant at 5 % level, pressure is not significant and the interactions indicated that only the interactions between w:w and temperature is significance at 1% level with a p-value of 0.008. The other interactions are not significant. However, the R-squared of 99.02 % has explained enough variations for the model to be considered.

Table 5 – ANOVA result for model representing tensile strength

Source	DF	Adj SS	Adj MS	F-value	P-value
Model	9	97.480	10.8311	5.53	0.037
Linear	**3**	**27.078**	**9.0259**	**4.61**	**0.067**
w:w	1	6.230	6.2304	3.18	0.135
Pressure	1	10.013	10.0128	5.11	0.073
Temperature	1	10.835	10.8345	5.53	0.065
Square	**3**	**38.570**	**12.8567**	**6.56**	**0.035**
w:w *w:w	1	4.327	4.3267	2.21	0.197
Pressure * Pressure	1	35.255	35.2545	18.00	0.008
Temperature * Temperature	1	1.914	1.9141	0.98	0.368
2-way interaction	**3**	**31.832**	**10.6106**	**5.42**	**0.050**
w:w *Pressure	1	26.368	26.3682	13.46	0.014
w:w *Temperature	1	0.265	0.2652	0.14	0.728
Pressure *Temperature	1	5.198	5.1984	2.65	0.164
Residual	5	9.794	1.9588		
Lack of fit	**3**	**9.793**	**3.2644**	**8160.94**	**0.000**
Pure error	**2**	**0.001**	**0.0004**		
Total	14	107.27			

Model summary

S	R-sq, %	R-sq(adj), %	R-sq(pred), %
1.39957	90.87	74.44	0.00

Table 6 – ANOVA result for model representing thermal conductivity

Source	DF	Adj SS	Adj MS	F-value	P-value
Model	9	0.07137	0.00793	56.37	0.000
Linear	**3**	**0.05154**	**0.01718**	**122.13**	**0.000**
w:w	1	0.04904	0.04904	348.60	0.000
Pressure	1	0.00075	0.00075	5.34	0.069
Temperature	1	0.00175	0.00175	12.43	0.017
Square	**3**	**0.01726**	**0.00575**	**40.90**	**0.001**
w:w *w:w	1	0.01635	0.01635	116.25	0.000
Pressure *Pressure	1	0.00041	0.00041	2.96	0.146
Temperature *Temperature	1	0.00149	0.00149	10.61	0.023
2-way interaction	**3**	**0.00257**	**0.00085**	**6.10**	**0.040**
w:w *Pressure	1	0.00004	0.00004	0.33	0.593
w:w *Temperature	1	0.00252	0.00252	17.96	0.008
pressure *Temperature	1	0.00000	0.00000	0.00	0.964
Residual	5	0.00070	0.00014		
Lack of fit	**3**	**0.00070**	**0.00023**	**571370.7**	**0.000**
Pure error	**2**	**0.000**	**0.000**		
Total	14	0.07207			

Model summary

S	R-sq, %	R-sq(adj), %	R-sq(pred), %
0.01186	99.02	97.27	84.39

Optimisation of Independent. The experimental parameters that produce maximum or minimum values of responses depend on optimisation criteria. Table 7 shows the best responses optimal results solution obtained.

Table 7 – Independent variables and responses optimal results

Fibre / binder (w:w)	Pressure (kg/m2)	Temperature (oC)	Density (kg/m3)	Water Absorption (%)	Tensile strength (N/m2)	Thermal conductivity (W/mK)	Desirability
1:1	500	92	151.50	9.05	16.90	0.106	0.62
1:2	100	30	204.40	4.74	16.80	0.206	0.60
1:1	500	30	163.30	13.70	13.40	0.122	0.58
1:1	500	30	144.42	16.60	12.8861	0.087	0.57
2:1	500	100	151.81	17.70	21.13	0.050	0.55

From Table 7, parameters in No1 was used in reproducing the *piliostigma thonningii* ceiling board composite for validation. The predicted results gave a minimal error difference when compared with the experimental results as shown in Table 8.

Table 8 – Validated results

Fiber / binder (w:w)	Press (kg/m2)	Temp (°C)	Density (kg/m3)		Water Absorption (%)		Tensile strength (N/m2)		Thermal Conductivity (W/mK)	
			(P)	(Ex)	(P)	(Ex)	(P)	(Ex)	(P)	(Ex)
1:1	500	92	151.50	151.92	9.05	9.03	16.90	16.90	0.106	0.09

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions were drawn from the 15 experimental runs results for the study.

1. The board's density increases as the ratio of the binder to the fibre increases. The boards have correspondingly lower densities compared to the standard boards

2. The board's percentage water absorption, some results fall within the conventional standard board values made from organic materials.

3. The boards recorded the lowest tensile strength ranging between 9.8 N/m and 19.32 N/m.

4. The *piliostigma thonningii* fibre boards have potentials for use as thermal insulation; the values fall within the requirement.

The following recommendations are made for further work:

The mechanical and thermal properties such as creep test, compressive strength, modulus of rupture, modulus of elasticity and thermal resistivity of the *piliostigma thonningii* fibre boards should be investigated.

The boards should be produced by the application of catalysts (initiator and accelerator) and evaluate their properties.

Since the boards were produced from organic materials, there is a need to examine the effect of insect attack which is mostly associated with organic products.

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REFERENCES

1. Abdullahi, I., & Umar A. A. (2010). Potentials of unsaturated polyester ground nut shell as material in building industry. *Journal of Engineering and Technology, 5*, 78–84.
2. ASTM International. (2012). *Standard Test Methods for Evaluating Properties of Wood-Base Fiber and Particle Panel Materials* (ASTM D1037-12). doi: 10.1520/d1037-12
3. ASTM International. (2016). *Standard Test Method for Dimensions and Density of Preformed Block and Board–Type Thermal Insulation* (ASTM C303-10(2016)e1). doi: 10.1520/C0303-10R16E01
4. ASTM International. (2018). *Standard Test Method for Water Absorption of Plastics* (ASTM D570-98(2018)). doi: 10.1520/D0570-98R18
5. Bledzki, A. (1999). Composites reinforced with cellulose based fibres. *Progress in Polymer Science, 24*(2), 221–274. doi: 10.1016/s0079-6700(98)00018-5
6. British Standard Institute. (2018). Methods of test for soils for civil engineering purposes. Chemical and electro-chemical testing (BS 1377-3:2018). Retrieved from https://shop.bsigroup.com/en/ProductDetail/?pid=000000000030351284
7. Chidumayo, E. Growth of Bauhinia thonningii Trees and Saplings over a Decade in a Savanna in Zambia: Interactions of Climate, Fire and Source of Regeneration. *Journal of Tropical Ecology,* 24(4), 407–415.
8. Dagwa, I. M., Builders, P. F., & Achebo, J. (2012). Characterization of Palm Kernel Shell Powder for use in Polymer Matrix Composites. *International Journal of Mechanical and Mechatronics Engineering, 12*(4), 88–93
9. Ekpunobi, U., Ohaekenyem, E., Ogbuagu, A., & Orjiako, E. (2015). The Mechanical Properties of Ceiling Board Produced from Waste Paper. *British Journal of Applied Science & Technology, 5*(2), 166–172. doi: 10.9734/bjast/2015/11627
10. JSTOR. (2019). Bauhinia thonningii. Retrieved March 1, 2019 , from https://plants.jstor.org/compilation/bauhinia.thonningii?searchUri=
11. Jústiz-Smith, N. G., Virgo, G. J., & Buchanan, V. E. (2008). Potential of Jamaican banana, coconut coir and bagasse fibres as composite materials. *Materials Characterization, 59*(9), 1273–1278. doi: 10.1016/j.matchar.2007.10.011
12. Klyosov, A. A. (2007). *Wood Plastic Composite*. New Jersey: John Wiley & Son Inc.
13. Nemli, G., & Aydın, A. (2007). Evaluation of the physical and mechanical properties of particleboard made from the needle litter of Pinus pinaster Ait. *Industrial Crops and Products, 26*(3), 252–258. doi: 10.1016/j.indcrop.2007.03.016
14. Oehlert, G. (2010). *A First Course in Design and Analysis of Experiments*. Minnesota: University of Minnesota.
15. Panyakaew, S., & Fotios, S. (2011). New thermal insulation boards made from coconut husk and bagasse. *Energy and Buildings, 43*(7), 1732–1739. doi: 10.1016/j.enbuild.2011.03.015
16. Schwartz, M. M. (1992). *Composite Materials Handbook* (2nd ed.). New York: McGraw-Hill.
17. Shaffer, J., Ashok, S., Antonovich, S. A., Sanders, Th. H., & Warner, S. (1999). *The Science and Design of Engineering Materials* (2nd ed.). New York: WCB/McGraw-Hill.
18. Tangjuank, S., & Kumfu, S. (2011). Particle Boards from Papyrus Fibers as Thermal Insulation. *Journal of Applied Sciences, 11*(14), 2640–2645. doi: 10.3923/jas.2011.2640.2645