



UNIVERSITI PUTRA MALAYSIA

***CHARACTERIZATION OF MILLET HUSK-FILLED HIGH DENSITY
POLYETHYLENE AND POLYLACTIC ACID COMPOSITES***

HAMMAJAM A. ABBA

FK 2018 81



**CHARACTERIZATION OF MILLET HUSK-FILLED HIGH DENSITY
POLYETHYLENE AND POLYLACTIC ACID COMPOSITES**

By

HAMMAJAM A. ABBA

**Thesis Submitted to the School of Graduate Studies, Universiti Putra
Malaysia, in Fulfillment of the Requirements for the Degree of
Doctor of Philosophy**

January 2018

COPYRIGHT

All material contained within the thesis, including without limitation text, logos, icons, photographs, and all other artwork, is copyright material of Universiti Putra Malaysia unless otherwise stated. Use may be made of any material contained within the thesis for non-commercial purposes from the copyright holder. Commercial use of material may only be made with the express, prior, written permission of Universiti Putra Malaysia.

Copyright © Universiti Putra Malaysia



DEDICATION

This thesis is dedicated to my family and the entire ummah for their support.



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

CHARACTERIZATION OF MILLET HUSK-FILLED HIGH DENSITY POLYETHYLENE AND POLYLACTIC ACID COMPOSITES

By

HAMMAJAM A. ABBA

January 2018

Chairman : Associate Professor Nur Ismarrubie Bt Zahari, PhD
Faculty : Engineering

The millet husk fiber (MHF) is an agricultural byproduct from millet (*pennisetum glaucum*). Currently, the use of thermoplastic composites produced from polymers filled with natural fibers has attracted the attention of many researchers globally. The main objective of this investigation was to study the potential of this agro waste as filler for thermoplastic composites as a substitute to synthetic fibers and other natural fibers. The fibers were treated with sodium hydroxide (NaOH) and pulverized to 250 μm . Fiber loadings of 10 %, 20 % 30 % and 40 % by weight were employed throughout the formulation. Test samples were prepared through melt blend technique followed by compression molding process. The mechanical properties; tensile, flexural and impact test specimens were specified according to ASTM standards and tested using universal testing machine (UTM). The thermal properties were characterized by using thermogravimetric analyzer (TGA). The microstructure observations of fractured surfaces of composites were studied by using scanning electron microscope (SEM). The investigation of water absorption in sea and rain water was determined. The biodegradability was carried out via soil burial technique in municipal and oxisol soils.

Tensile strength of untreated fiber millet husk powder (MHP) filled high density polyethylene (HDPE) and MHP filled poly lactic acid (PLA) composites decreased with increased fiber loading but slightly improved for treated fibers composites. While the tensile modulus of both treated and untreated fibers composites increased by increasing the fiber loadings. Flexural strength of the MHP-HDPE treated fiber composites increased as loading increased, while MHP-PLA composites decreased as loading increased. PLA composites exhibit better flexural properties for treated fiber composites. The flexural

modulus for both treated and untreated fiber composites of MHP-PLA and MHP-HDPE increased as fiber loadings increases. The impact properties of treated and untreated fibers MHP-HDPE, MHP-PLA, composites drastically decreased as fiber loading increased. Water absorption increased as fiber loading increased. Composites immersed in sea water uptake at higher rate compare to those immersed in rain water. Thermal degradations of untreated and treated fiber composites show slight difference in terms of weight loss, while decomposition rate varies as the fiber loading increased. Biodegradability in municipal soil showed higher rate of degradation compared to oxisol soil. The degradation level for treated and untreated fiber composites differs slightly in both types of soil. MHP-PLA composites degrade faster in both municipal and oxisol soil compare to MHP-HDPE composites. The fiber treatment has little impact on their biodegradability rates. In view of all the findings, it was appropriate to conclude that millet husk fiber filled thermoplastic is a promising composite.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENCIRIAN SEKAM BIJIRIN YANG DIPENUHI POLIETILENA KETUMPATAN TINGGI DAN KOMPOSIT ASID LAKTIK POLI

Oleh

HAMMAJAM A. ABBA

Januari 2018

Pengerusi : Profesor Madya Nur Ismarrubie Bt Zahari, PhD
Fakulti : Kejuruteraan

Serat sekam millet (MHF) adalah hasil sampingan dari millet (*pennisetum glaucum*). Pada masa ini, penggunaan komposit termoplastik yang dihasilkan daripada polimer bercampur dengan serat semulajadi telah menarik perhatian ramai penyelidik di seluruh dunia. Objektif utama penyelidikan ini adalah untuk mengkaji potensi sisa agro ini sebagai pengisi untuk komposit termoplastik menggantikan serat sintetik dan serat semula jadi lain. Serat ini telah dirawat dengan natrium hidroksida (NaOH) dan dilumatkan kepada 250 μ m. Pemuatan serat sebanyak 10%, 20% 30% dan 40% berat digunakan sepanjang formulasi. Sampel ujian disediakan melalui teknik campuran cair yang diikuti dengan proses pengacuan mampatan. Sifat mekanik; spesimen uji tegangan, lenturan dan kesan ditentukan mengikut piawaian ASTM dan diuji menggunakan mesin ujian sejagat (UTM). Ciri-ciri termal telah dicirikan dengan menggunakan penganalisis termogravimetrik (TGA). Pemerhatian mikrostruktur permukaan patah komposit telah dikaji dengan menggunakan mikroskop elektron scanning (SEM). Penyiasatan penyerapan air di laut dan air hujan telah ditentukan. Keabadian biodegradasi dilakukan melalui teknik pengebumian tanah di tanah perbandaran dan oxisol.

Kekuatan tegangan serat sekam tepung dedaunan (MHP) yang tidak diisi polietilena ketumpatan tinggi (HDPE) dan komposisi asid laktik poli (MHA) yang diisi dengan MHP berkurangan dengan peningkatan beban gentian tetapi sedikit bertambah baik untuk komposit serat terawat. Walaubagaimanapun modulus tegangan kedua-dua komposit gentian yang terawat dan tidak dirawat meningkat dengan meningkatkan beban serat. Kekuatan lenturan komposit serat MHP-HDPE yang dirawat meningkat apabila beban meningkat, manakala komposit MHP-PLA menurun apabila

beban meningkat. Komposit PLA mempamerkan sifat lentur yang lebih baik untuk komposit serat yang terawat. Modulus lenturan untuk kedua-dua komposit gentian yang terawat dan tidak dirawat oleh MHP-PLA dan MHP-HDPE meningkat apabila kenaikan beban serat meningkat. Ciri-ciri kesan gentian yang dirawat dan tidak dirawat MHP-HDPE, MHP-PLA, komposit secara drastik berkurangan apabila beban serat meningkat. Penyerapan air meningkat apabila beban gentian meningkat. Komposit yang direndam dalam pengambilan air laut pada kadar yang lebih tinggi berbanding dengan yang direndam dalam air hujan. Degradasi termal komposit serat yang tidak dirawat dan dirawat menunjukkan sedikit perbezaan dari segi penurunan berat, manakala kadar penguraian berbeza-beza apabila beban serat meningkat. Biodegradasi di tanah perbandaran menunjukkan kadar degradasi yang lebih tinggi berbanding dengan tanah oxisol. Tahap penguraian untuk komposit serat yang dirawat dan tidak dirawat sedikit berbeza di kedua-dua jenis tanah. Komposit MHP-PLA mengurai lebih cepat di dalam tanah perbandaran dan oxisol berbanding komposit MHP-HDPE. Serat terawat mempunyai sedikit kesan terhadap kadar biodegradasinya. Berdasarkan semua penemuan, adalah wajar untuk membuat kesimpulan bahawa termoplastik yang terisi serat sekam adalah komposit yang berpotensi.

ACKNOWLEDGEMENTS

I thank Almighty Allah for giving me this precious opportunity and strength to carry out this study. My sincere appreciation to my supervisor Associate Professor Dr Nur Ismarrubie Zahari, co-supervisors Prof. Ir.Dr Mohd Salit Sapuan and Associate Prof. Dr Zulkiffle Leman for spending their ample time and strength in guiding me throughout the period of my study.

I acknowledge my family for their patient during the entire period of study. My appreciations to the entire lecturers and staffs of the Department of Mechanical and Manufacturing Engineering, Universiti Putra Malaysia for their moral assistance during the course of studies.

Let me also extend my appreciation to my senior colleagues, classmates and friends whom we share views and ideas during this research. I also acknowledge the contributions of following persons; Engr. (Dr) Mohammed M Maina, Dr Hafiz, Dr Tarajo Buba Ahmad, Hajiya Ladidi Godowoli, Engr (Dr) M.U Kallamu and Ms Hassana for moral their support.

This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Nur Ismarrubie Binti Zahari, PhD

Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Sapuan Mohammed Salit, PhD

Professor Ir,
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Zulkiffle Leman, PhD

Associate Professor
Faculty Engineering
Universiti Putra Malaysia
(Member)

ROBIAH BINTI YUNUS, PhD

Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software

Signature: _____ Date: _____

Name and Matric No: Hammajam A. Abba, GS39781

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) were adhered to.

Signature: _____

Name of Chairman
of Supervisory
Committee:

Associate Professor
Dr. Nur Ismarrubie Binti Zahari

Signature: _____

Name of Member
of Supervisory
Committee:

Professor Ir,
Dr. Sapuan Mohammed Salit

Signature: _____

Name of Member
of Supervisory
Committee:

Associate Professor
Dr. Zulkiffle Leman

TABLE OF CONTENTS

	Page
ABSTRACT	i
ABSTRAK	iii
ACKNOWLEDGEMENTS	v
APPROVAL	vi
DECLARATION	viii
LIST OF TABLES	xiv
LIST OF FIGURES	xv
LIST OF ABBREVIATIONS	xxiii
LIST OF NOTATIONS	xxvi
 CHAPTER	
 1 INTRODUCTION	 1
1.1 Background	1
1.2 Problem statements	2
1.3 Work scope	2
1.4 Significance of the study	3
1.5 Objectives	3
1.6 Thesis structure	3
 2 LITERATURE REVIEW	 5
2.1 Introduction	5
2.2 Cereal waste fibers composites	7
2.3 Natural fibers and it treatment	13
2.3.1 Other natural fibers use as filler/reinforcement	17
2.3.2 Advantages of natural fiber	20
2.3.3 Disadvantages of natural fiber	21
2.3.4 Potentials of natural fiber	22
2.3.5 Current and future trend of natural fiber composites	22
2.4 Millet husk	23
2.5 Millet husk fiber size and profile	24
2.6 Origin of millet and its distribution	25
2.7 Millet producing area	27
2.8 Matrix	28
2.9 Millet husk composites	29
2.10 Summary	31

3	METHODOLOGY	32
3.1	Introduction	32
3.2	Materials and methods	33
3.2.1	Millet husk	33
3.2.2	Fiber moisture absorption	33
3.2.3	Chemical composition of the millet husk fiber	34
3.2.4	Fundamental (Elemental) analysis of millet husk fiber	35
3.2.5	Fiber extraction processing and treatment (mercerization)	35
3.2.6	Millet husk fiber pulverizations	37
3.2.7	FTIR Characterization	38
3.3	Matrices and binder	38
3.3.1	HDPE	39
3.3.2	PLA	39
3.3.3	Test equipment	39
3.4	Composites fabrications	40
3.4.1	Density of composites	43
3.4.2	Compression molding process	44
3.5	Mechanical properties test specimen preparation and testing processes	45
3.6	Thermogravimetric characterizations	50
3.7	Water absorption test	51
3.8	Biodegradability test	53
3.9	SEM Microstructural observations	56
3.10	Summary	56
4	RESULTS AND DISCUSSION	57
4.1	Introduction	57
4.2	Fiber moisture analysis	57
4.3	Chemical composition analysis of the fiber	58
4.4	Fundamental composition analysis of the fiber	58
4.5	FTIR Spectroscopy analysis	59
4.6	Mechanical properties of MHP-HDPE and MHP-PLA composites	61
4.6.1	Effect of fiber loadings on tensile strength of untreated MHP-PLA and MHP- HDPE composites	61
4.6.2	Effect of fiber loadings on tensile modulus of untreated MHP-HDPE and MHP-PLA composites	65
4.6.3	SEM microstructural examinations of untreated MHP- HDPE and MHP-PLA composites	66
4.6.4	Effect of fiber loadings on flexural strength of untreated MHP-HDPE and MHP-PLA composites	68
4.6.5	Effect of fiber loadings on flexural modulus of untreated MHP-HDPE and MHP-PLA composites	70
4.6.6	Impact strength of untreated MHP-HDPE and MHP-PLA composites	71

4.6.7	Effect of fiber loadings on tensile strength of treated MHP-HDPE and MHP-PLA composites	72
4.6.8	Effect of fiber loadings on tensile modulus of treated MHP-HDPE and MHP-PLA composites	74
4.6.9	Effect of fiber loadings on flexural strength of treated MHP-HDPE and MHP-PLA composites	76
4.6.10	Effect of fiber loadings on flexural modulus of treated MHP-HDPE MHP- HDPE-MAPE and MHP-PLA composites	78
4.6.11	Effect of fiber loadings on impact strength of treated MHP-HDPE and MHP-PLA composite	79
4.6.12	SEM microstructural examinations of treated MHP-HDPE and MHP-PLA composites	80
4.7	Water absorption analysis	83
4.7.1	Effects of water absorption on MHP-HDPE and MHP-PLA composites	83
4.7.2	Thickness swelling of MHP-HDPE and MHP-PLA composites	87
4.7.3	Effect of water absorption on the tensile properties of MHP-HDPE and MHP-PLA composites	90
4.7.4	Effects of water absorption on flexural properties of MHP-HDPE and MHP-PLA composites	96
4.7.5	Effect of water absorption on the Impact properties of MHP-HDPE and MHP-PLA composites	100
4.7.6	SEM Microstructural examinations of MHP-HDPE and MHP-PLA composites after water absorption	103
4.8	Thermogravimetric analysis	105
4.8.1	Fiber thermogravimetric analysis	106
4.8.2	The effects of fiber loading on thermal properties of MHP-HDPE and MHP-PLA composites	108
4.8.3	Effect of fiber treatment of the thermal properties of MHP-HDPE and MHP-PLA composites	111
4.9	Soil biodegradation analysis	114
4.9.1	Weight loss analysis of MHP-HDPE and MHP-PLA composites	114
4.9.2	Biodegradability of MHP-HDPE and MHP-PLA composites	116
4.9.3	Visual examinations of MHP-HDPE and MHP-PLA composites	119
4.9.4	The mechanical properties of MHP-HDPE and MHP-PLA composites after soil burial	123
4.9.5	Microstructural examinations of MHP-HDPE and MHP-PLA composites after soil burial	128
4.10	SUMMARY	132

5	CONCLUSIONS AND RECOMMENDATIONS	134
5.1	Conclusions	134
5.2	Recommendations	135
	REFERENCES	137
	APPENDICES	153
	BIODATA OF STUDENT	180
	LIST OF PUBLICATIONS	181



LISTS OF TABLES

Table	Page
2.1 Average mechanical properties testing results of cereal huskcomposites	8
2.2 Chemical compositions of some husks fiber	9
2.3 Thermal properties of cereal husk fiber composites	12
2.4 Major Millet producingareas(Millet Production by Country in 1000 MT)FAO, (2002)	28
3.1 Brabender twin rotor internal mixer condition	40
3.2 Formulation of MHP-HDPE and MHP-PLA	40
3.3 Compression molding condition for composite formation	45
4.1 Moisture content results for millet husk at 105 °C for 24 hrs	58
4.2 Chemical composition of millet husk	58
4.3 Fundamental compositions of millet husk fiber	59

LISTS OF FIGURES

Figure	Page
2.1 Classification of natural fibers (Akil et al, 2011)	7
2.2 SEM micrographs of: (a) barley husk and (b) coconut shell husk (Andrzej et al, 2010)	9
2.3 SEM micrographs of rice husk filled HDPE composite (a) Rice husk powder(b) without coupling agent (c) with coupling agent	10
2.4 Tensile and flexural strength of rice husk composites with and without process additives (Pathapulakkal et al, 2005b)	10
2.5 Tensile and flexural modulus of rice husk composites with and without process additives (Pathapulakkal et al, 2005b)	11
2.6 Surfaces morphology of husks before and after treatment by NaOH: (a) untreated rice husk; (b)–(d) treated rice husk with NaOH concentration of 2%, 5% and 10%, respectively; (e) untreated wheat husk; (f)–(h) treated wheat husk with NaOH concentration of 2%, 5% and 10%, respectively (Thi et al, 2014)	12
2.7 Thermogravimetric curves of the neat PLA and biocomposites with untreated and treated rice husk (Thi et al, 2014)	13
2.8 Thermo-gravimetric curves of the Kenaf composites	14
2.9 Comparison of (a) tensile strength, and (b) flexural strength of the Barley husk composites before and after water absorption	15
2.10 Comparison of Impact strength of the green composites after water absorption (Deka et al, 2013)	15
2.11 Moisture absorption behavior of thermoplastic SPS with different amount of agar (Jumaidin et al, 2016)	16
2.12 Water absorption of composites during 150 days of immersion in normal water (Sanjay and Yogesha, 2016)	16
2.13 Tensile strength (left hand scale) and tensile modulus (right hand scale) of the green composites (Deka et al, 2013)	17
2.14 Thermogravimetric analysis (TGA) curves	18

2.15	SEM micrograph of fractured flax fiber reinforced laminates (Petrucci et al., 2013)	18
2.16	Flexural strength (left hand scale) and modulus (right hand scale) of the green Composites (Deka et al, 2013)	19
2.17	Impact strength of the green composites (Deka et al, 2013)	20
2.18	A millet farm in Maiduguri, Nigeria	24
2.19	Millet husks	25
2.20	Production contribution of the top 10 millet producing countries in 2005 (Source : U.S.A 2017)	26
2.21	Millet production records and global millet production map www.http:archive (Accessed, 2017)	28
2.22	Effects of Fiber Loadings and Sizes on Tensile Strength of MH-HDPE Composites (Hammajam et al, 2013)	30
2.23	Effects of Fiber Loadings and Sizes on Tensile Modulus of MH-HDPE Composites (Hammajam et al, 2013)	30
3.1	Activities flow chart	32
3.2	Millet anatomies	33
3.3	Fiber alkali reactions during mercerization	36
3.4	Mercerization process of millet husk fibers	36
3.5	Mercerized (treated) millet husk fibers	36
3.6	Pulverized millet husk, a) treated and b) untreated	37
3.7	(a) Sensitive scale (b) Blending process (c) PC-Internal mixer	43
3.8	Composites pellets of different fiber loadings	43
3.9	Composites after solidification	46
3.10	Control samples (a) neat HDPE and (b) neat PLA	46
3.11	Flexural Test specimens 150 x 12.7 x 3 mm	48
3.12	Schematic diagrams of tensile and flexural test specimen	48

3.13	Specimens tensile failure mode	49
3.14	Specimens after flexural testing	49
3.15	Impact test specimens	50
3.16	Schematic diagrams of impact test specimens	50
3.17	Water absorption test specimen immerse in water	53
3.18	Absorption test specimens measurement	53
3.19	Soil burial tests	56
4.1	FTIR spectroscopy of neat HDPE, MHP and MHP-HDPE composites	60
4.2	FTIR spectroscopy of neat PLA, MHP and MHP-PLA composites	60
4.3	Loads vs. Extension Curves of Neat HDPE	63
4.4	Loads vs. Extension Curves of Neat PLA	63
4.5	Effects of fiber loadings on tensile strengths of treated/untreated MHP-HDPE and MHP-PLA composites	64
4.6	Elongation at break of treated/untreated MHP-HDPE and MHP-PLA composites	64
4.7	Effects of fiber loadings on tensile modulus of treated/untreated MHP-HDPE and MHP-PLA composites	66
4.8	SEM micrographs showing microstructures of untreated MHP-HDPE composites with different fiber loading; (a) 10 % (b) 20 %, (c) 30 %, and (d) 40%	67
4.9	EM micrographs showing microstructures of untreated fiber MHP-PLA composites with different fiber loading; (a) 10 % (b) 20 %, (c) 30 %, and (d) 40%	68
4.10	Effects of fiber loadings on flexural strengths of untreated MHP-HDPE and MHP-PLA composites	69
4.11	Effects of fiber loadings on flexural modulus of untreated MHP-HDPE and MHP-PLA composites	70

4.12	Effects of fiber loadings on impact strength of untreated MHP-HDPE and MHP-PLA composites	72
4.13	Effects of fiber loading tensile strengths of treated MHP-HDPE, MHP-PLA, and MHP-MAPE-HDPE composites	74
4.14	Elongation at break of treated fiber composites	74
4.15	Effects of fiber loadings on tensile modulus of treated fibers MHP-HDPE, MHP-PLA, and MHP-MAPE-HDPE composites	76
4.16	Effects of fiber loadings on flexural strengths of treated MHP-HDPE, MHP-PLA, and MHP-HDPE-MAPE composites	77
4.17	Effects of fiber loadings on flexural modulus of treated MHP-HDPE, MHP-PLA, and MHP-MAPE-HDPE composites	78
4.18	Effects of fiber loadings on impact strengths of treated MHP-HDPE, MHP-PLA, and MHP-MAPE-HDPE composites	80
4.19	SEM micrographs showing microstructures of treated MHP-HDPE composites with different fiber loading; (a) 10 % (b) 20 %, (c) 30 %, and (d) 40%	82
4.20	SEM micrographs showing microstructures of treated MHP-PLA composites with different fiber loading; (a) 10 % (b) 20 %, (c) 30 %, and (d) 40%	83
4.21	Percentage of weight gain as a function of time for HDPE and HDPE-MHP composites immersed in sea water at room temperature (23°C)	85
4.22	Percentage of weight gain as a function of time for PLA and PLA-MHP composites immersed in sea water at room temperature (23°C)	86
4.23	Percentage of weight gain as a function of time for HDPE and HDPE-MHP composites immersed in rain water at room temperature (23°C)	86
4.24	Percentage of weight gain as a function of time for PLA and PLA-MHP composites immersed in rain water at room temperature (23°C)	87
4.25	Thickness swelling of treated fiber MHP-HDPE and MHP-PLA composites in sea water as function fiber loading	88
4.26	Thickness swelling of treated fiber MHP-HDPE and MHP-PLA composites in rain water as function fiber loading	88

4.27	Thickness swelling of MHP-HDPE composites in Sea water as function of immersion time	89
4.28	Thickness swelling of MHP-PLA composites in Sea water as function of immersion time	89
4.29	Thickness swelling of MHP-HDPE composites in rain water as function of immersion time	90
4.30	Thickness swelling of MHP-PLA composites in rain water as function of immersion time	90
4.31	Effects of fiber loading on tensile strength of treated MHP-HDPE and MHP-PLA composites after water absorption (sea water). D=Dry and W=Water immersed	93
4.32	Effects of fiber loading on tensile modulus of treated MHP-HDPE and MHP-PLA composites after water absorption (sea water). D=Dry and W=Water immersed	93
4.33	Elongation at break of treated fiber composites water immersed (sea water)	94
4.34	Elongation at break of treated fiber composites water immersed (rain water)	94
4.35	Effects of fiber loading on tensile strength of treated MHP-HDPE and MHP-PLA composites after water absorption (rain water). D=Dry and W=Water immersed	95
4.36	Effects of fiber loading on tensile modulus of treated MHP-HDPE and MHP-PLA composites after water absorption (rain water). D=Dry and W=Water immersed	95
4.37	Effects of fiber loadings on flexural strengths of treated MHP-HDPE and MHP-PLA composites after water absorption (sea water). D=Dry and W=Water immersed	97
4.38	Effects of fiber loadings on flexural modulus of treated MHP-HDPE and MHP-PLA composites after water absorption (sea water). D=Dry and W=Water immersed	97
4.39	Effects of fiber loading on flexural strength of untreated MHP-HDPE and MHP-PLA composites after water absorption (sea water). D=Dry and W=Water immersed	98

4.40	Effects of fiber loading on flexural modulus of untreated MHP-HDPE and MHP-PLA composites after water absorption (sea water). D=Dry and W=Water immersed	98
4.41	Effects of fiber loadings on flexural strength of untreated MHP-HDPE and MHP-PLA composites after water absorption (rain water). D=Dry and W=Water immersed	99
4.42	Effects of fiber loadings on flexural modulus of untreated MHP-HDPE and MHP-PLA composites after water absorption (rain water). D=Dry and W=Water immersed	99
4.43	Impact strength of untreated fiber composites immersed in sea water with respect to dry composites (W=water immerse; D= before water immersion)	101
4.44	Impact strength of untreated fiber composites immersed in rain water with respect to dry composites (W=water immerse; D= before water immersion)	102
4.45	Impact strength of treated fiber composites immersed in sea water with respect to dry composites (W=water immerse; D= before water immersion)	102
4.46	Impact strength of treated fiber composites immersed in sea water with respect to dry composites (W=water immerse; D= before water immersion)	103
4.47	SEM micrographs showing microstructure of MHP-HDPE composites after water absorption (a) fiber agglomerate, (b) fracture running along the interface, (c) fiber–matrix debonding due to fiber cut and (d) improve strength due better adhesion	104
4.48	SEM micrographs showing microstructure of MHP-PLA composites after water absorption (a) fiber agglomerate, (b) fracture running along the interface, (c) fiber–matrix debonding due to fiber cut and (d) improve strength due better adhesion	105
4.49	TGA thermogram of MHP	107
4.50	Derivative thermogram of MHP	107
4.51	TGA of neat HDPE and treated MHP-HDPE composites	110
4.52	DTG of neat HDPE and treated MHP-HDPE composites	110
4.53	TGA of neat PLA and treated MHP-PLA composites	111

4.54	DTG of neat PLA and treated MHP-PLA composites	111
4.55	TGA of untreated MHP-HDPE composites	112
4.56	DTG of untreated MHP-HDPE composites	113
4.57	TGA of untreated MHP-PLA composites	113
4.58	DTG untreated MHP-PLA composites	114
4.59	Hydrolysis mechanism of PLA in soil	117
4.60	Percentage weight loss as function burial time of MHP-HDPE composites soil burial (municipal soil)	117
4.61	Percentage weight loss as function burial time of MHP-HDPE composites soil burial (oxisol soil)	118
4.62	Percentage weight loss as function burial time of MHP-PLA composites soil burial (municipal soil)	118
4.63	Percentage weight loss as function burial time of MHP-PLA composites soil burial (oxisol soil)	119
4.64	Visual images of 40%, 30%, 20%, and 10% fiber loading MHP-HDPE composites after 120days burial in Municipal soil	120
4.65	Visual images of 40 %, 30 %, 20 %, and 10 % fiber loading MHP-HDPE composites after 120 days burial in Oxisol soil	120
4.66	Visual images of 10 %, 20 %, 30 %, and 40 % fiber loading MHP-PLA composites after 120days burial in Municipal soil	121
4.67	Visual images of 40%, 30%, 20%, and 10% fiber loading MHP-PLA composites after 120days burial in Oxisol soil	121
4.68	Visual images of (a) Neat PLA (b) Neat HDPE after 120 days burial in municipal soil	122
4.69	Visual images of (a) Neat PLA (b) Neat HDPE after 120 days burial in Oxisol soil	123
4.70	Tensile strengths of MHP-HDPE and MHP-PLA composites after soil burial (Municipal soil)	125
4.71	Elongation at break of MHP-HDPE and MHP-PLA composites soil burial (Municipal soil)	125

4.72	Elongation at break of MHP-HDPE and MHP-PLA composites soil burial (Oxisol soil)	126
4.73	Tensile modulus of MHP-HDPE and MHP-PLA composites after soil burial (Municipal soil)	126
4.74	Flexural strengths of MHP-HDPE and MHP-PLA composites after soil burial (Municipal soil)	127
4.75	Flexural modulus of MHP-HDPE and MHP-PLA composites after soil burial (Municipal soil)	127
4.76	SEM micrographs showing microstructures of MHP-HDPE composites (a) 10 % (b) 20 % (c) 30 % (d) 40 % fiber loadings of after soil burial in Municipal soil	129
4.77	SEM micrographs showing microstructures of MHP-HDPE composites (a) 10 % (b) 20 % (c) 30 % (d) 40 % fiber loadings of after soil burial in Oxisol soil	130
4.78	SEM micrographs showing microstructures of MHP-PLA composites (a) 10 % (b) 20 % (c) 30 % (d) 40 % fiber loadings of after soil burial in Municipal soil	131
4.79	SEM micrographs showing microstructures of MHP-PLA composites (a) 10 % (b) 20 % (c) 30 % (d) 40 % fiber loadings of after soil burial in Oxisol soil	132

LIST OF ABBREVIATIONS

ADF	Acid Detergent Fiber
ADL	Acid Detergent Lignin
ATR	Attenuated Total Reflection infrared
ASTM	America Standard Testing Materials
AS	Standard Association of Australia
BC	Before Christ
C	Carbon
CH ₄	Methane
CO	Carbon Monoxide
CO ₂	Carbon Dioxide
cm	Centimeter
cm ⁻¹	Wave number
CTAB	Cetyltrimethylammonium Bromide
DTG	Derivative Thermogravimetric
FTIR	Fourier Transforms Infrared
FFT	Fast Fourier Transforms
FL	Fiber Loading
g	Gram
GPa	Giga Pascal
H	Hydrogen
ha	Hectare
HDPE	High Density Polyethylene
hr	Hour

H ₂ SO ₄	Sulpheric Acid
H ₂ O	Water
IR	Infrared
ISO	International Standard Organization
KBr	Potassium Bromide
kg	Kilogram
kJ	Kilo Joule
kN	Kilo Newton
kV	Kilovolt
MAPE	Maleic Anhydride Grafted Polyethylene
Mc	Moisture content
M _{cw}	Mixer capacity
MHF	Millet Husk Fiber
MHP	Millet Husk Powder
min.	Minute
mL	Milliliter
Mol	Mole
MPa	Mega Pascal
N	Nitrogen
N	Newton
NaOH	Sodium Hydroxide
NDF	Neutral Detergent Fiber
O	Oxygen
OH	Hydroxyl

PC	Personal computer
PE	Polyethylene
PLA	Poly Lactic Acid
pH	Power of Hydrogen
ROM	Rule of Mixer
rpm	Revolution Per Minute
SEM	Scanning Electron Microscope
STD	Standard Deviation
UTM	Universal testing machine
TGA	Thermogravimetric Analysis

LIST OF NOTATIONS

NOTATION	UNIT
b Width	m
h Height	m
l Length	m
D Diameter	mm
d Thickness	m
V Volume	m ³
°C Temperature	°C
S Displacement	mm
W Load at yield (maximum load)	N/m
I Moment of area	mm
F Force applied on the test specimen	kN
ϵ Strain of the test sample	m/m
A Crosssectional area of the test specimen	m ²
δ Applied stress on the test specimen	N/m ²
E Flexural modulus	GPa
σ Flexural strength	MPa
μm Micrometer	
% Percentage	
W_t Weight percentage	
W_{hdpe} Weight of high density polyethylene	
W_{mf} Weight of millet fiber	
W_m Weight of matrix	

W_f Weight of fiber

T_s Glass temperature

T_r Transient temperature



LIST OF APPENDICES

Appendix	Page
A Chemical and fundamental compositions of MHP	153
B FTIR Spectroscopy	155
C Tensile properties of MHP-HDPE and MHP-PLA composites	159
D Flexural properties of MHP-HDPE and MHP-PLA composites	164
E Impact properties of MHP-HDPE and MHP-PLA composites	168
F TGA Thermograms of MHP-HDPE and MHP-PLA composites	171

CHAPTER 1

INTRODUCTION

1.1 Background

The use natural fibers for composite material manufacturing have received great attention because of their sustainability and renewability. Research and advancement on natural fiber composites are continually rising and their function is growing into novel fields of usage (Jumaidin et al., 2017; Kiruthika, 2017; Merkel et al., 2014; Sapuan and Mansor, 2014). The attributes of natural fibers such as availability, low density, cost-effective, renewability, and biodegradability act as agents in the replacement of usual fillers/reinforcements of composites, like carbon and glass. However, problems associated with the use of synthetics materials have forced legislation to enact laws that protect the environment in many countries around the globe (Sain and Panthapulakkal, 2006; Samper et al., 2015; Sapuan and Mansor, 2014). In addition, the search for low cost and superior materials in many advanced technology fields such as automotive, nautical, building as the alternative to synthetic materials has received prompt attention (Mahjoub et al., 2014).

Therefore, the utilization of these fibers can save the environment and humanity from becoming the house for microorganisms that harbor diseases. The use of thermoplastic polyethylene (PE) in demanding technology applications have increased in recent time (Boopalan et al., 2013). Due to the attractive properties of high melting point, high density and good chemical inertness, it becomes an important choice for husk, fiber filler, compounding and blending work (Ridzuan et al., 2016). Because of its nature, it can be remelted and recycled for various purposes, thus PE composites are profitable and environmentally friendly. Although good work has been done in a variety of areas on agro waste composites, the current literature on millet husk-filled poly lactic acid has not been reported with respect to their composite formations and thus this topic forms the basis for this study. Therefore, the usage of millet husk in natural fiber thermoplastic or polymer composite manufacturing in Sahel sub-Saharan African countries is limited. In the research on the millet husk here, the chemical compositions, fiber size chemistry and thermal degradation characteristics were determined with the aim to establish the viability in the processing and production of composites. Consequently, it is suggested as a possible filler for plastic composites, since research has shown that synthetic fibers have a direct influence on the environment and this substitute material does not endanger the natural forest product which is waning in resource and becoming costly.

1.2 Problem statements

This study tries to find solutions to the environmental and health-related problems caused by agricultural wastes such as respiratory infections, diarrhea, malaria, intestine nematode, trachoma, sleeping sickness etc. as reported by Smith et al., (2004); Smith et al., (2000); and WHO (2002) through converting the waste into polymer-filled composites. Millet husks fiber is an agro waste left on the farm site after harvest. Due to the underutilization of this waste, it became home for microorganisms that harbor diseases and consequently resulted in environmental pollution in Sub-Saharan Africa where large amount of millet husks are deposited on farm lands. According to the world health report, an estimated 24% of the world disease burden and 23% of all deaths can be associated with environmental factors (WHO, 2002). However, the greater percentages are from developing nations. This study seeks a way of converting this waste into fillers for plastic composites applications.

1.3 Work scope

The investigation of agro waste millet husk powder (MHP)-filled high-density polyethylene (HDPE) and poly lactic acid (PLA) composites was conducted in this work. The study started with the preparation of millet husk, poly lactic acid, sodium hydroxide and high-density polyethylene and is followed by the treatment of fibers, testing and characterization of the composites. Municipal soil (city soil, black with loose sandy appearance) was obtained from Damaturu city area, Nigeria with a pH value of 6.8 and soil temperature of 34 °C in June 2015. Oxisol soil (tropical rain forest soil), sometimes called red earth, was obtained from Lekki area of Lagos. Seawater was collected from the Atlantic Ocean off the shore of Lagos, Nigeria in May 2015. Millet husk powder was used as the composite filler while high-density polyethylene and poly lactic acid were used as polymer matrices. The effects of fiber loading on the mechanical, physical, and thermal properties were investigated. In addition, the biodegradability, microstructure and water absorption of the composites were also investigated.

1.4 Significance of the study

This investigation presents the findings on the applicability of millet husk fiber as filler in high-density polyethylene (HDPE) and poly lactic acid (PLA) composites. Several other vital investigations were carried out on some cereal fibers to develop industrial products. There is a large quantity of millet husks across sub-Saharan Africa that was left as agro wastes; however, the development of these husks into poly lactic acid-filled composite was not reported. Millet husk is selected for this investigation as the filler because of its availability, environmental and health impact. Furthermore, the forecast cost benefits include domestic utilities, environmental safety through end product recycling, preventing damages to ecosystems and occupation of utilizable land, as well as cost reduction in manufacturing. It is presumed that these composites could be used in domestic products (lampshade, partition board) and office utilities especially where load bearing is not a critical parameter.

1.5 Objectives

The aim of the investigation is to see the possibility of using millet husk powder (MHP) fiber as the filler in high-density polyethylene (HDPE) and poly lactic acid (PLA) polymer matrix to form composites. The specific objectives are;

- To evaluate the effect of fiber treatment on the mechanical properties of MHP-filled HDPE and PLA composites.
- To determine the effect of water absorption on the mechanical properties of MHP-filled HDPE and PLA composites.
- To evaluate the biodegradability of MHP-filled HDPE and PLA composites.
- To determine the effect of fiber loading on the thermal properties of MHP-filled HDPE and PLA composites.

1.6 Thesis structure

This thesis is structured into five chapters as follows; Chapter 1 presents the background of studies, the work scope, the significance, and the objectives of the study as well as the thesis structure.

Chapter 2 contains the literature assessment of research work in different areas relevant to this study. It began with fiber treatment, fabrications and properties characterizations of the composite products made from agro waste husk, fiber and plastic. Mechanical, microstructure, physical, thermogravimetric, degradability and water absorption properties of millet husk

were reviewed. Studies of composite preparation and properties are also included in this section.

Chapter 3 describes the methodology of the study. It also presents the techniques to determine the physical, microstructure, thermogravimetric, degradability, water absorption and mechanical properties of the composites. The preparation steps of the composites were also presented.

Chapter 4 reports the results and discussion of the study. The discussion on the mechanical properties of the composites such as tensile, flexural and impact tests was presented. The morphology of the fractured surface of the composites using the scanning electron microscope (SEM) was also presented. In addition, the physical, water absorption, biodegradability, thermogravimetric analysis of the composites were investigated and the findings presented.

Finally, Chapter 5 presents the conclusion and recommendations for further investigations on the study.

REFERENCES

- Abubakar, M. S., and Ahmad, D. (2010). Pattern of energy consumption in millet production for selected farms in Jigawa, Nigeria. *Australia Journal of Applied Sciences*, 4(4), 665-672.
- Adhikiry, K. B., Pang, S., and Staiger, M. P. (2008). Dimensional stability and mechanical behaviour of wood-plastic composite based on recycling and virgin high-density polypropylene (HDPE). *Composites Part B: Engineering*, 39, 807-815.
- Ahmad, N., and Park, Y. W. (2012). Green Economy Key to Overcoming Resource Constraints in Asia-Pacific. UN <http://www.un.org/apps/news/story.asp>. (Accessed August, 2012).
- Akhtara, M. N., Abu Bakar, S., Fadzly Radzib, M. K., Ismailb, N. F., and Razab, M. R. (2016). Influence of alkaline treatment and fiber loading on the physical and mechanical properties of kenaf/polypropylene composites for variety of applications. *Progress in Natural Science: Materials International*, 26, 657-664.
- Akil, H.M., Omar, M.F., Mazuki, A.A.M., Safiee, S., Ishak, Z.A.M., and Bakar, A.A. (2011). Kenaf fiber reinforced composites: A review. *Materials and Design*, 32, 4107-4121.
- Alawar, A., Hamed, A. M., and Al-Kaabi, K. (2009). Characterization of treated date palm tree fiber as composite reinforcement. *Composites Part B: Engineering*, 40(7), 601-606.
- Alomayri, T., Assaedia, H., Shaikhc, F. U. A., and Lowa, I. M. (2014). Effect of water absorption on the mechanical properties of cottonfabric-reinforced geopolymers. *Journal of Asian Ceramic Societies* 2, 223–230.
- Alvarez, V. A., Ruseckaite, R. A., and Vázquez, A. (2006). Degradation of sisal fibre/Mater Bi-Y biocomposites buried in soil. *Polymer Degradation and Stability*, 91(12), 3156-3162.
- Aminullah, A., Syed, M. S. J., Azlan, N., Mohd, N. H., and Moh'd, Z. A. I. (2010). Effect of filler composition and incorporation of additives on the mechanical properties of polypropylene composites with high loading lignocellulosic materials. *Journal of Reinforced Plastic and Composite*, 29, 3115-3121.
- Andiç-Çakir, Ö., Sarikanat, M., Tüfekçi, H. B., Demirci, C., and Erdoğan, Ü. H. (2014). Physical and mechanical properties of randomly oriented coir

fiber–cementitious composites. *Composites Part B: Engineering*, 61, 49-54.

Andrzej, K., Bledzki A.K, Abdullah A.M, and Jürgen V. (2010). Barley husk and coconut shell reinforced polypropylene composites: The effect of fibre physical, chemical and surface properties. *Composites Science and Technology* 70, 840–846.

Anja, T. Jr and Sarita, S. (2010). Suitability of foxtail millet (*setaria italica*) and Barny and millet for development of low glycemic index biscuits. *Malay journal of nutrition*, 16,(3), 361-8.

AS1289B1. (2012). Standard Association of Australia for Determination of soil moisture content by oven-drying methods AS Standard

Ashori, A., and Nourbakhsh, A. (2010). Performance properties of microcrystalline cellulose as a reinforcing agent in wood plastic composites. *Composites Part B: Engineering*, 41(7), 578-581.

Ashori, A., Sheshmani, S., and Farhani, F. (2013). Preparation and characterization of bagasse/HDPE composites using multi-walled carbon nanotubes. *Carbohydrate Polymers*, 92(1), 865-871.

ASTM D256. (2010). Standard Test Methods for Determining the Izod Pendulum Impact Resistance of Plastics ASTM International

ASTM D570-98. (2010). Standard Test Methods for Water Absorption of Plastic and Composites ASTM International

ASTM D790. (2010). Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics Composites ASTM International

ASTM D792. (2000). Standard Test Methods for Density and Specific Gravity (relative density) of plastic composites ASTM International

ASTM D1037. (2010). Standard Test Methods for Evaluating the Properties of Fiber base Composites Materials ASTM International

ASTM D3039. (2010). Standard Test Methods for Tensile Properties of Polymer Matrix Composites Materials ASTM International

ASTM D4442. (2010). Standard Test Methods for Direct Moisture Content of plastics Composites ASTM International

ASTM G160-12. (2012). Standard Practice for Evaluating Degradation and Microbial Susceptibility of nonmetallic Materials by Soil Burial ASTM International

- Ayfer, D. Ç., Hülya, K., and Fatih, M. (2011). Tea mill waste fibers filled thermoplastic composites: the effects of plastic type and fiber loading. *Journal of Reinforced Plastics and Composites*, 30: , 833.
- Azwa, Z. N., Yousif, B. F., Manalo, A. C., and Karunasena, W. (2013). A review on the degradability of polymeric composites based on natural fibres. *Materials & Design*, 47, 424-442.
- Babaei, I., Madanipour, M., Farsi, M., and Farajpoor, A. (2014). Physical and mechanical properties of foamed HDPE/wheat straw flour/nanoclay hybrid composite. *Composites Part B: Engineering*, 56, 163-170.
- Behjat, T., Russly, A. R., Luqman, C. A., Yus, A. Y., and Nor Azowa, I. (2009). Effect of PEG on the biodegradability studies of Kenaf cellulose - polyethylene composites. *International Food Research Journal*, 16, 243-247.
- Behzad, K. (2011). Preparation and characterization of lignocellulosic material filled polyethylene composite foams. *Journal of Thermoplastic Composite Materials*, 1-10.
- Belaadi, A., Bezazi, A., Bouchak, M., Scarpa, F., and Zhu, C. (2014). Thermochemical and statistical mechanical properties of natural sisal fibres. *Composites Part B: Engineering*, 67, 481-489.
- Bledzki, A. K., Mamun, A. A., Bonnia, N. N., and Ahmad, S. (2012). Basic properties of grain by-products and their viability in polypropylene composites. *Industrial Crops and Products*, 37(1), 427-434.
- Boopalan, M., Niranjanaa, M., and Umapathy, M. J. (2013). Study on the mechanical properties and thermal properties of jute and banana fiber reinforced epoxy hybrid composites. *Composites Part B: Engineering*, 51, 54-57.
- Bouafif, H., Koubaa, A., Perre, P., and Cloutier, A. (2009). Effects of fiber characteristic on the physical and mechanical properties of wood fiber composites. *Compos Part A-Applied Science and Manufacturing* 40, 1975-1981.
- Burgstaller, C. (2014). A comparison of processing and performance for lignocellulosic reinforced polypropylene for injection moulding applications. *Composites Part B: Engineering*, 67, 192-198.
- Carlone, P., Sorrentino, L., and Kent, R. (2016). 5.11 Process Control for Polymeric Composite Manufacture Reference Module in Materials Science and Materials Engineering: Elsevier.

- Chandak, S. P. (2010). waste biomass utilization. United Nation Environment Programme (UNEP), 1-16.
- Chaniga Chuensangjuna, Chiravoot Pechyenb, and Sirisansaneeyakula, S. (2013). Degradation behaviors of different blends of polylactic acid buried in soil, 10th Eco-Energy and Materials Science and Engineering (EMSES2012). Energy Procedia 34 73 – 82.
- Chhavi, A and Sarita, S. (2012). Evaluation of composites of millet breads for sensory and nutritional qualities and glycemic response. US national library of science, national institute of health.
- Colin, W., Harold C, and Charles E W. (2004) Encyclopedia of grain science. Missouri: Elsevier Academic Press.
- Collar, C., Jimeneje, T., Conte, P., and Fadda, C. (2014). Impact of ancient cereal, pseudocereals and legumes on starch hydrolysis and antiradical activities of technologically viable blended breads. Journal of Carbohydrate Polymer, 20, 149-58.
- Crespo J E., Sánchez L., García D., and López J. (2010). Study of the Mechanical and Morphological Properties of Plasticized PVC Composites Containing Rice Husk Fillers. Journal of Reinforced Plastics and Composites, 27, 229-232.
- Davis, G., and Song, J. H. (2006). Biodegradable packaging base on raw materials from crops and their impact on waste management. industrial crop production, 23, 147.
- Davoodi, M. M., Sapuan, S. M., Ahmad, D., Aidy, A., Khalina, A., and Jonoobi, M. (2012). Effect of polybutylene terephthalate (PBT) on impact property improvement of hybrid kenaf/glass epoxy composite. Materials Letters, 67(1), 5-7.
- Deka, H., Mansuri, M., and Mohanty, A. (2013). Renewable resource based “all green composites” from Kenaf biofiber and poly(furfuryl alcohol) biorein. Industrial Crops and Products, 41, 94-101
- Deng, H., Reynolds, C. T., Cabrera, N. O., Barkoula, N. M., Alcock, B., and Peijs, T. (2010). The water absorption behaviour of all-polypropylene composites and its effect on mechanical properties. Composites Part B: Engineering, 41(4), 268-275.
- Dhakal, H. N., Zhang, Z. Y., and Richardson, M. O. W. (2006). Effect of water absorption on the mechanical properties of hemp fibre reinforced unsaturated polyester composites. Composites Science and Technology, 67(7-8), 1674-1683.

- Dominique, M. R., Georget D.M.R., Abd Elmoneim, O., Elkhalfa, A. E. O., and Beltom, P. S. (2012). Structural changes in kafirin extracted from a white type II tannin sorghum. *Journal of Cereal Science*. *Journal of Cereal Science*, 106-111.
- Donald Garlotta. (2001). A literature review of poly lactic acid. *Journal of Polymers and the Environment*, 9(2), 121-134.
- El-Abbassi, F. E., Assarar, M., Ayad, R., and Lamdouar, N. (2015). Effect of alkali treatment on Alfa fibre as reinforcement for polypropylene based eco-composites: Mechanical behaviour and water ageing. *Composite Structures*, 133, 451-457.
- El-Sabbagh, A. (2014). Effect of coupling agent on natural fibre in natural fibre/polypropylene composites on mechanical and thermal behaviour. *Composites Part B: Engineering*, 57, 146-155.
- Ester Rojo, Virginia Alonso M, Mercedes Oliet, Belén Del Saz-Orozco, and Rodriguez, F. (2015). Effect of fiber loading on the properties of treated cellulose fiber-reinforced phenolic composites. *Composites: Part B:Engineering*, 68, 185-192.
- FAO,Millet production index. Accessed 24 October 2017 from <http://www.fao.org/countryprofiles/index/en/NGA>.
- Faruk, O., Bledzki, A. K., Fink, H.-P., and Sain, M. (2012). Biocomposites reinforced with natural fibers: 2000–2010. *Progress in Polymer Science*, 37(11), 1552-1596.
- Fernandes, E. M., Correlo, V. M., Mano, J. F., and Reis, R. L. (2014). Polypropylene-based cork–polymer composites: Processing parameters and properties. *Composites Part B: Engineering*, 66, 210-223.
- Fiore, V., Di Bella, G., and Valenza, A. (2015). The effect of alkaline treatment on mechanical properties of kenaf fibers and their epoxy composites. *Composites Part B: Engineering*, 68, 14-21.
- Gani, A., and Naruse, I. (2007). effect of cellulose and lignin content on pyrolysis and combustion characteristics of several types of biomass. *Review energy*, 32, 649-661.
- Gloria A M. (2001). Properties of oil palm (*elaeis guineensis*) empty fruit bunch fibre polypropylene composites. PhD Thesis, university putra malaysia, Malaysia.

- González, Daniel, S., Valentín, P., and Juan, C. (2011). Manufacture of fibrous reinforcements for biocomposites and hemicellulosic oligomers from bamboo. *Chemical Engineering Journal*, 167(1), 278-287.
- Graupner, N., Ziegmann, G., Wilde, F., Beckmann, F., and Müssig, J. (2016). Procedural influences on compression and injection moulded cellulose fibre-reinforced polylactide (PLA) composites: Influence of fibre loading, fibre length, fibre orientation and voids. *Composites Part A: Applied Science and Manufacturing*, 81, 158-171.
- Habibi, M. K., Samaei, A. T., Gheshlaghi, B., Lu, J., and Lu, Y. (2015). Asymmetric flexural behavior from bamboo's functionally graded hierarchical structure: Underlying mechanisms. *Acta Biomaterialia*, 16, 178-186.
- Hadjadj, A., Jbara, O., Tara, A., Gilliot, M., Malek, F., Maafi, E. M., and Tighzert, L. (2016). Effects of cellulose fiber content on physical properties of polyurethane based composites. *Composite Structures*, 135, 217-223.
- Hammajam, A. A., Ismarrubie, Z. N., and Sapuan, M. S. (2013). Review of Agro Waste Plastic Composites Production. *Journal of Minerals and Materials Characterization and Engineering*, 5, 612-624.
- Hamzeh, Y., Ziabari, K. P., Torkaman, J., Ashori, A., and Jafari, M. (2013). Study on the effects of white rice husk ash and fibrous materials additions on some properties of fiber–cement composites. *Journal of Environmental Management*, 117, 263-267.
- Hassan, S. B., Oghenevweta, J. E., and Aigbodion, V. S. (2012). Morphological and mechanical properties of carbonized waste maize stalk as reinforcement for eco-composites. *Composites Part B: Engineering*, 43(5), 2230-2236.
- Hazarika, A., Mandal, M., and Maji, T. K. (2014). Dynamic mechanical analysis, biodegradability and thermal stability of wood polymer nanocomposites. *Composites Part B: Engineering*, 60(0), 568-576.
- Hee-Soo Kim, Han-Seung Yang, and Hyun-Joong Kim. (2005). Biodegradability and Mechanical Properties of Agro-Flour–Filled Polybutylene Succinate Biocomposites. *Applied Polymer Science*, 97, 1513–1521.
- Heuze, V., and Tran, G. (2012). Pearl Millet (*Pennisetum Glaucum*) grain. Programme by INRA, CIRAD, ATZ and FAO, August 27, 2012

- Ibrahim, M. M., Dufresne, W., El-Zawwawy, W., and Agblevor, F. A. (2010). Banana fibres and microfibrils as lignocellulosic reinforcement in polymer composites. *Carbohydrate Polymer*, 81, 811-819.
- Ishiaku, U. S., Pang, W. S., Lee, W. S., and Ishak, A. M., (2002). Biodegradability and Mechanical Properties of Agro-Flour-Filled Polybutylene Succinate Biocomposites. *European Polymer Material*, 38, 393-403.
- Ismail, H., Mohamad, Z., and Bakar, A. A. (2003). Comparative study on processing, mechanical properties, thermo-oxidative aging, water absorption, and morphology of rice husk powder and silica filler in polystyrene/styrene butadiene rubber blends . *Journal of Polymer Plastics Technology and Engineering*, 42(1), 81-103.
- Joseph, S., Appukuttan, S. P., Kenny, J. M., Puglia, D., Thomas, S., and Joseph, K. (2010). Dynamic mechanical properties of palm oil microfibril-reinforce natural rubber composites. *Journal of Applied Science*, 117, 1298-1308.
- Jumaidin, R., Sapuan, S. M., Jawaid, M., Ishak, M. R., and Sahari, J. (2017). Thermal, mechanical, and physical properties of seaweed/sugar palm fibre reinforced thermoplastic sugar palm Starch/Agar hybrid composites. *International Journal of Biological Macromolecules*, 97(Supplement C), 606-615.
- Kabir, M. M., Wang, H., Lau, K. T., and Cardona, F. (2012). Chemical treatments on plant-based natural fibre reinforced polymer composites: An overview. *Composites Part B: Engineering*, 43(7), 2883-2892.
- Kabir, M. M., Wang, H., Lau, K. T., and Cardona, F. (2013). Tensile properties of chemically treated hemp fibres as reinforcement for composites. *Composites Part B: Engineering*, 53, 362-368.
- Kafodya, I., Xian, G., and Li, H. (2015). Durability study of pultruded CFRP plates immersed in water and seawater under sustained bending: Water uptake and effects on the mechanical properties. *Composites Part B: Engineering*, 70, 138-148.
- Karger-Kocsis, J., Mahmood, H., and Pegoretti, A. (2015). Recent advances in fiber/matrix interphase engineering for polymer composites. *Progress in Materials Science*, 73, 1-43.
- Kim J K., Hu C, Woo R, and Sham M L. (2005). The effects of water aging on the interphase region and interlaminar fracture toughness in polymer-glass composite. *Composites Science Technology*, 64(13-14), 2185-2195.

- Kim Birm-June, Yao Fei, Han Guangping, Wang Qingwen, and Wu Qinglin. (2013). Mechanical and physical properties of core-shell structured wood plastic composites: Effect of shells with hybrid mineral and wood fillers. *Composites Part B: Engineering*, 45(1), 1040-1048.
- Kim, H.-S., Kim, H.-J., Lee, J.-W., and Choi, I.-G. (2006). Biodegradability of bio-flour filled biodegradable poly(butylene succinate) bio-composites in natural and compost soil. *Polymer Degradation and Stability*, 91(5), 1117-1127.
- Kim Man Tae, Yo, R. K., Jung Inhwa, Park Soo Jin, and Hui David. (2014). Influence of seawater absorption on the vibration damping characteristics and fracture behaviors of basalt/CNT/epoxy multiscale composites. *Composites Part B: Engineering*, 63, 61-66.
- Kiruthika, A. V. (2017). A review on physico-mechanical properties of bast fibre reinforced polymer composites. *Journal of Building Engineering*, 9(Supplement C), 91-99.
- Kuciel, S., Jakubowska, P., and Kuźniar, P. (2014). A study on the mechanical properties and the influence of water uptake and temperature on biocomposites based on polyethylene from renewable sources. *Composites Part B: Engineering*, 64, 72-77.
- Kumar, M. G., and Bavan, S. D. (2010). Potential use of natural fiber composite materials in India. *Journal of Reinforced Plastics and Composites*, 29 (24), 3600–3613.
- Kwon, H.-J., Sunthornvarabhas, J., Park, J.-W., Lee, J.-H., Kim, H.-J., Piyachomkwan, K., and Cho, D. (2014). Tensile properties of kenaf fiber and corn husk flour reinforced poly(lactic acid) hybrid bio-composites: Role of aspect ratio of natural fibers. *Composites Part B: Engineering*, 56, 232-237.
- Leman, Z., Sapuan, S. M., Saifol, A. M., Maleque, M. A., and Ahmad, M. M. H. M. (2008). Moisture absorption behavior of sugar palm fiber reinforced epoxy composites. *Materials & Design*, 29(8), 1666-1670.
- Liu, W., Drzal, L. T., Mohanty, A. K., and Misra, M. (2007). Influence of processing methods and fiber length on physical properties of kenaf fiber reinforced soy based biocomposites. *Composites Part B: Engineering*, 38(3), 352-359.
- Lucas, N., Bienaice, C., Belloy, C., Queneulie, M., Silvestre, F., and Nava-Saucedo, J. E. (2008). Polymer degradation: Mechanisms and estimation techniques -a review. *Chemosphere*, 73, 429-442.

- Majid, N.A., Abu Bakar, S., Fadzly, M.K., Ismail, N.F., Raza, M.R., Norhamidi, M., Muhammad, A.K. (2016). Influence of alkaline treatment and fiber Loading on the physical and mechanical properties kenaf/polypropylene composites for variety of applications. *Progress in Natural Science: Material International*, 26, 657-664.
- Maggana, C., and Pissis, P. (1999). Water sorption and diffusion studies in an epoxy resin system. *Journal of Polymer Science Part B: Polymer Physics*, 37(11), 1165-1182.
- Mahjoub, R., Yatim, J. M., Mohd Sam, A. R., and Hashemi, S. H. (2014). The tensile properties of kenaf fiber due to various conditions of chemical fiber surface modification. *Construction and Building Materials*, 55, 103-133.
- Maizatunisa, O., Nor Azowa, I., Che Mohd, R., Nazarudin, Z., and Zahurin, H. (2012). Biodegradability Analysis of KBF Reinforced Poly(lactic acid) Biocomposites. *Advanced Materials Research* 576, 434-437.
- Malucelli, G., Carosio, F., Alongi, J., Fina, A., Frache, A., and Camino, G. (2014). Materials engineering for surface-confined flame retardancy. *Materials Science and Engineering: Reports*, 84, 1-20.
- Manikandan, V., Winowlin Jappes, J. T., Suresh Kumar, S. M., and Amuthakkannan, P. (2012). Investigation of the effect of surface modifications on the mechanical properties of basalt fibre reinforced polymer composites. *Composites Part B: Engineering*, 43(2), 812-818.
- Mansor, M. R., Sapuan, S. M., Zainudin, E. S., Nuraini, A. A., and Hambali, A. (2013). Hybrid natural and glass fibers reinforced polymer composites material selection using Analytical Hierarchy Process for automotive brake lever design. *Materials & Design*, 51, 484-492.
- Mannuramah, M., Yenagi, N., and Orsat, V. (2015). Quality evaluation of little millet (*Panicum miliara*) incorporated functional bread. *Journal of Food Science Technology*, 52(12), 8357-63.
- Marsh, G. (2009). Composites are the future for GE Aviation, Hamble. *Reinforced Plastics*, 53(3), 24-29.
- Maslinda, A. B., Abdul Majid, M. S., Ridzuan, M. J. M., Afendi, M., and Gibson, A. G. (2017). Effect of water absorption on the mechanical properties of hybrid interwoven cellulosic-cellulosic fibre reinforced epoxy composites. *Composite Structures*, 167, 227-237.
- McDonald, A. G., Gallangher, L. W., and Sundar, S. T. (2005). The effect of wood surface modification and particle size on wood plastic composite performance. In: *proceeding of the 18th International Conference on*

wood fiber plastic composites, Madison, W.I May 23-25. forest product society, 2801 marshall Ct., Madison, WI 53705-2295, USA, 163-171.

McGee, B. (2006). Folder corn/grain corn. area and production Retrieved Accessed 21 December, 2007.

Mehta, G., Mohanty, A. K., Thayer, K., Misra, M., and Drzal, L. T. (2005). novel biocomposites sheet molding compounds for low cost housing panel applicattions. *Journal of polymer and environment*, 13, 169-175.

Mengeloglu, F., and Kabakci, A. (2008). Determination of thermal properties and morphology of eucalyptus wood residue filled high density polyethylene composites. *International Journal of molecular science*, 9, 107-119.

Mengeloglu, F., Matuana, L. M., and King, J. (2000). Effect of impact modifiers on properties of rigid PVC/wood-fiber composites. . *Journal of Vinyl Additive Technology*, 6 153-157.

Mengeloglu K., and Karakus, K. (2008). Polymer Composites from recycled high density polyethylene and waste lignocellulosic materials. *Fresen Environment Bulletin*, 17, 211-217.

Merkel, K., Rydarowski, H., Kazimierczak, J., and Bloda, A. (2014). Processing and characterization of reinforced polyethylene composites made with lignocellulosic fibres isolated from waste plant biomass such as hemp. *Composites Part B: Engineering*, 67, 138-144.

Michael, K. B. (2005). *Engineering Material: properties and selection* (8th ed ed.). upper saddle river, new jersey Columbus, Ohio: pearson prentice hall.

Miller, S. A., Srubar Iii, W. V., Billington, S. L., and Lepech, M. D. (2015). Integrating durability-based service-life predictions with environmental impact assessments of natural fiber–reinforced composite materials. *Resources, Conservation and Recycling*, 99, 72-83.

Mohanty, A., Misra, M., and Drzal, L. (2001). Surface modification of natural fibers and performance of the resulting biocomposites: An overview. *composite Interfaces*, 8, 313-343.

Mohanty, A., Misra, M., and Drzal , L. (2002). sustainable biocmposites from renewable resources: opportunity and challenges in the green materials world. *Journal of polymer and environment*, 10, 19-26.

Nangia, S. (2000). Towards faster trains role of composites Retrieved 23th Dec., 2001

- Narendar, R., and Priya Dasan, K. (2014). Chemical treatments of coir pith: Morphology, chemical composition, thermal and water retention behavior. *Composites Part B: Engineering*, 56, 770-779.
- Neena, G., and Inderjeet, K. (2013). Soil burial biodegradation studies of starch grafted polyethylene and identification of *Rhizobium meliloti* there from. *Journal of Environmental Chemistry and Ecotoxicology*, 5(6), 147-158.
- Norul Izani, M. A., Paridah, M. T., Anwar, U. M. K., Mohd Nor, M. Y., and H'ng, P. S. (2013). Effects of fiber treatment on morphology, tensile and thermogravimetric analysis of oil palm empty fruit bunches fibers. *Composites Part B: Engineering*, 45(1), 1251-1257.
- Nourbakhsh, A., Ashori, A., and Kazemi Tabrizi, A. (2014). Characterization and biodegradability of polypropylene composites using agricultural residues and waste fish. *Composites Part B: Engineering*, 56, 279-283.
- Obi Reddy, K., Uma Maheswari, C., Shukla, M., Song, J. I., and Varada Rajulu, A. (2013). Tensile and structural characterization of alkali treated *Borassus* fruit fine fibers. *Composites Part B: Engineering*, 44(1), 433-438.
- Okubo, K., Fujii, T., and Yamashita, N. (2005). Improvement of interfacial adhesion in bamboo polymer composite enhanced with micro-fibrillated cellulose. *JSME International Journal Science A: Solid Mechanics Materials Engineering*, 48, 199-204.
- Oliveira, C., Cunha, F., and Andrade, C. (2010). Evaluation of biodegradability of different blends of polystyrene and starch buried in soil. *Macromolecular Symposium*, 290, 115-120.
- Orue, A., Jauregi, A., Peña, C., Labidi, J., Eceiza, A., and Arbelaiz, A. (2013). The effect of surface modifications on sisal fiber properties and sisal/poly (lactic acid) interface adhesion. *Composites Part B: Engineering*, 34, 336-347.
- Panaitecu, D. M., Vuluga, Z., Ghiurea, M., Iorga, M., Nicolae, C., and Gabor, R. (2015). Influence of compatibilizing system on morphology, thermal and mechanical properties of high flow polypropylene reinforced with short hemp fibers. *Composites Part B: Engineering*, 69, 286-295.
- Panthapulakkal, Sain, M., and Law, S. (2005a). Enhancement of processability of rice husk filled high density polyethylene composites profiles. *Journal of Thermoplastic Composite Materials*, 18:, 445-459.
- Panthapulakkal, Sain, M., and Law, S. (2005b). Effect of coupling agent on rice husk filled with HDPE extruded profiles. *International Journal of Polymer*, 54, 373-381.

- Panthapulakkal S., and Sain, M. (2007). Agro-residue reinforced HDPE composites: Fibre characterization and analysis of composites properties. *Composite Part A* :2007, 38, 1445–1454.
- Patel, B. M. (2012). Animal nutrition in Western India, A review of workdone from 1961-1965. Anand, India Council of Agricultural Resources.
- Petchwattana, N., and Covavisaruch, S. (2013). Effects of Rice Hull Particle Size and Content on the Mechanical Properties and Visual Appearance of Wood Plastic Composites Prepared from Poly(vinyl chloride). *Journal of Bionic Engineering*, 10(1), 110-117.
- Petrucci, R., Santulli, C., Puglia, D., Sarasini, F., Torre, L., and Kenny, J.M. (2013). Mechanical characterisation of hybrid composite laminates based on basalt fibres in combination with flax, hemp and glass fibres manufactured by vacuum infusion. *Materials and Design*, 49,728-735.
- Pritchard, G. (2004). Two technologies merge: wood plastic composites. *Plastic additive and compounding*, 6, 18-21.
- Ramzy, A., Beermann, D., Steuernagel, L., Meiners, D., and Ziegmann, G. (2014). Developing a new generation of sisal composite fibres for use in industrial applications. *Composites Part B: Engineering*, 66, 287-298.
- Ray, D., and Rout, J. (2005). in *Thermosets Biocomposites* Ed by A.K Mohanty, M. Misra & L.T Drzal (Eds.), (pp. 310-313).
- Ricardo, H., Gustavo, E., Martinez, T., Gonzalo, C. E., Pedro, I. G. C., Cesar, M. B., and Osvaldo, M. D. (2010). A preliminary study on the preparation of wood plastic composites from urban wastes generated in Merida, Mexico with potential applications as building materials. *Journal of Waste Management and Research*, 28(9), 838-847.
- Ridzuan, M. J. M., Abdul Majid, M. S., Afendi, M., Aqmariah Kanafiah, S. N., Zahri, J. M., and Gibson, A. G. (2016). Characterisation of natural cellulosic fibre from *Pennisetum purpureum* stem as potential reinforcement of polymer composites. *Materials & Design*, 89, 839-847.
- Rojo, E., Alonso, M. V., Oliet, M., Del Saz-Orozco, B., and Rodriguez, F. (2015). Effect of fiber loading on the properties of treated cellulose fiber-reinforced phenolic composites. *Composites Part B: Engineering*, 68, 185-192.
- Rowell, R. M., Sanadi, A.R., Caufield, D.F., and Jacobson, R.E. (1997). Utilization of natural fibres in plastic composites: Problems and Opportunities. In: Leao AL, Carvalho FX and Frollini. E (eds.) *Lignocellulosic plastic composites*, Wisconsin: University of Rio de Janeiro, 23-51.

- Rozita, O., Idris, A., Yunus, R., Khalid, K., and Aidalsma, M. I. (2011). characterization of empty fruit bunch for microwave assisted pyrolysis. *Fuel*, 90, 1536-1544.
- Sain, M., and Panthapulakkal, S. (2006). Bioprocess preparation of wheat fiber and characterization. *Industrial crop production*, 23, 1-8.
- Salmah, H.; Koay, S.C.; and Hakimah, O.(2012). Surface modification of coconut shell powder filled poly lactic acid biocomposites. *Journal of Thermoplastic Composite Materials*, 26(6),809-819.
- Samper, M. D., Petrucci, R., Sánchez-Nacher, L., Balart, R., and Kenny, J. M. (2015). New environmentally friendly composite laminates with epoxidized linseed oil (ELO) and slate fiber fabrics. *Composites Part B: Engineering*, 71, 203-209.
- Sanjay, M .R and Yogesha, B. (2016). Studies on Natural/Glass Fiber Reinforced Polymer Hybrid Composites: An Evolution: 5th International Conference on Materials Processing and Characterization. *Materials Today: Proceedings*, 4, 2739–2747.
- Sapuan, S. M., and Bachtiar, D. (2012). Mechanical Properties of Sugar Palm Fibre Reinforced High Impact Polystyrene Composites. *Procedia Chemistry*, 4, 101-106.
- Sapuan, S. M., and Maleque, M. A. (2005). Design and fabrication of natural woven fabric reinforced epoxy composite for household telephone stand. *Materials & Design*, 26(1), 65-71.
- Sapuan, S. M., and Mansor, M. R. (2014). Concurrent engineering approach in the development of composite products: A review. *Materials & Design*, 58, 161-167.
- Shanshan, L., Yanhua, Z., Jiyu, G., and Haiyan, T. (2017). Biodegradation behavior and modelling of soil burial effect on degradation rate of PLA blended with starch and wood flour. *Colloids and Surfaces B: Biointerfaces*, 159(Supplement C), 800-808.
- Shih, Y.-F., Cai, J.-X., Kuan, C.-S., and Hsieh, C.-F. (2012). Plant fibers and wasted fiber/epoxy green composites. *Composites Part B: Engineering*, 43(7), 2817-2821.
- Shobana, S., Krishnawamy, K., Sudha, V., Malleshi, N.G., Anjana, R.M., Palaniappan, L and Mohan, V. (2013). Finger millet: a review of its nutritional properties, processing, and plausible health benefits. *Advance Food Nutrition Resource*, 69, 1-39.

- Shukla, K and Srivastava, S. (2014). Evaluation of finger millet incorporated noddles for nutritive values and glycemic index. *Journal of Food Science Technology*, 51(3), 527-34.
- Simone, M., Rosa, L., Evelise, F.S., Carlos, A.F., Sonia M.B.N. (2009). Studies on the properties of rice husk filled polypropylene composites- effect of maleate polypropylene. *Journal of Material Science*, 12(3), 333-338.
- Singh, G., Kaur, N., Bhunia, H., Bajpai, P. K., and Mandal, U. K. (2011). Degradation behaviors of linear low-density polyethylene and poly(Llactic acid) blends. *Journal of Applied Polymer Science*, 124, 1993-1998.
- Siracusa, G., La Rosa, A. D., Siracusa, V., and Trovato, M. (2001). Eco-Compatible Use of Olive Husk as Filler in Thermoplastic Composites. *Journal of Polymers and the Environment*, 9(4), 157-161.
- Smith, K. R., Mehta S, and Maeuzahl-Feuz M. (2004). Indoor air pollution from solid household industrial fuel. In: Ezzati M, Lopez AD, Rodger A, Murray CJL. Paper presented at the Comparative quantification of health risks, Geneva.
- Smith, K. R., Samet J M, Romieu I, and Bruce N. (2000). Indoor air pollution in developing countries and acute lower respiratory infections in children. *Thorax*, 55(6), 518-532.
- Sobhy, M. S., and Tammam, M. (2010). The influence of fiber length and concentration on the physical properties of wheat husk fibers rubber composites. *International Journal of Polymer Science*, 43,342-351.
- Spiridon, I., Leluk, K., Resmerita, A. M., and Darie, R. N. (2015). Evaluation of PLA–lignin bioplastics properties before and after accelerated weathering. *Composites Part B: Engineering*, 69, 342-349.
- Stefani, P. M., Garcia, D., Lopez, J., and Jimenes, A. (2005). Thermogravimetric analysis of composites obtained from sintering of rice husk scrap tire mixture. *Journal of Thermal Analysis and Calorimetry*, 81(2), 315-320.
- Stevens, M. P. (1990). *polymer chemistry; an introduction*. New York: Oxford University Press.
- Steward, R. (2007). Wood fibre composite: Fierce competition drives advances in equipment, materials and processes. *Journal of Plastic Engineering*, 63, 21-28.

- Suddel, B. C., and Evans, W. (2005). Natural fiber, biopolymers and biocomposites. In: Mohanty AK, Misra M, Drzal LT, editors. New York: Taylor and Francis; . polymer and environment, 231-259.
- Tagliavia, G., Porfiri, M., and Gupta, N. (2012). Influence of moisture absorption on flexural properties of syntactic foams. *Composites Part B: Engineering*, 43(2), 115-123.
- Taib, R. M., Ramarad, S., and Ishak, Z. A. M. (2010). Effect of accetylation and MAPE on the properties of steam exploded Acacia mangium fibre-HDPE composites. *Journal of Reinforced Plastic Composite*, 29, 431-444.
- Tajvidi, M., Falk, R. H., and Hermanson, J. C. (2006). Effect of natural fibers on thermal and mechanical properties of natural fiber polypropylene composites studied by dynamic mechanical analysis. *Journal of Applied Polymer Science*, 101(6), 4341-4349.
- Thi, P.T.T.; Jean, C.B.; and Anne, B. (2014). Rice and Einkon wheat husks reinforced poly lactic acid (PLA) biocomposites: Effects of alkaline and saline surface treatments of husks. *Industrial Crops and Products*, 58, 111-124.
- Tokoro, R., Vu, D. M., Okubo, K., and Fujiura, T. (2008). How to improve the mechanical properties of polylactic acid with bamboo fibers. *Journal of material science*, 43, 775-787.
- Tserki, V., Matzimos, P., and Panayiotou, C. (2006). Biodegradable Aliphatic Polyesters, Part II: Synthesis and Characterization of Chain Extended Poly(butylenes succinate-co-butylene adipate). *Polymer Degradation Stability*, 91, 367-372.
- U.S.A. (2017). United State Department of Agriculture Report. USA
- USA, (2002) Millet producing area. Accessed 23 October 2017. From http://archive.gramene.org/species/setaria/foxtailmillet_maps_and_stats.html.
- Wang, J., and Ye, L. (2015). Structure and properties of polyvinyl alcohol/polyurethane blends. *Composites Part B: Engineering*, 69, 389-396.
- Wang Y., Yeh FC., Lai SM., Chan HC., and Shen HF. (2003). Effectiveness of functionalized polyolefins as compatibilizers for polyethylene/wood flour composites. *Polymer Engineering Science*, 43, 933-945.
- WHO. (2002). World health report 2002-Reducing risks, promoting healthy life. Geneva.

Williams, T., Hosur, M., Theodore, M., Netravali, A., Rangari, A., and Jeelani, S. (2011). Time Effects on Morphology and Bonding Ability in Mercerized Natural Fibers for Composite Reinforcement. *International Journal of Polymer Science*, 13, 1-10.

Yicheng Dua, Tongfei Wub, Yan, N., Mark T, Kortschot, and Farnood, R. (2014). Fabrication and characterization of fully biodegradable natural fiber-reinforced poly(lactic acid) composites. *Composites: Part B: Engineering*, 56, 717-723.

Zhang, D., Milanovic, N. R., Zhang, Y., Su, F., and Miao, M. (2014). Effects of humidity conditions at fabrication on the interfacial shear strength of flax/unsaturated polyester composites. *Composites Part B: Engineering*, 60, 186-192.

Zhong, J., Zhang, L., Yu, J., Tan, T., and Zhang, X. (2010). Studies of different kinds of fiber penetrating on the properties of PLA/Sweet sorghum fiber composites,. *Journal of Applied Polymer Science*, 117, 1298-1308.

Zhou, A., Tam, L.-h., Yu, Z., and Lau, D. (2015). Effect of moisture on the mechanical properties of CFRP–wood composite: An experimental and atomistic investigation. *Composites Part B: Engineering*, 7163-73.