Table of Contents

Title of the thesis

		Page No.
	Thesis Certificate	ii
	Acknowledgement	V
	Table of contents	vii
	List of figures List of Tables	xi xiii
	List of Tubies List of abbreviations and symbols	xiv
	Preface	xvi
	Introduction	1-10
1.1	Overview	1
1.2	Polymer	2
1.3	Agro-waste	5
1.3.1	Classification of Agro-waste	6
1.3.2	Chemical composition of Agro-waste	7
	Literature Review and Objectives	11-45
2.1	Literature review	11
2.1.1	Feedstock for packaging application	11
2.1.1.1	Polyethylene	11
2.1.1.2	Polypropylene	12
2.1.1.3	Agro-waste	12
2.1.2	Composite material	14
2.1.3	Agro-waste characterization	15
2.1.4	Packaging film characterization	16
2.1.5	Types of synthesis process involved	17
2.1.5.1	Extrusion molding	17
2.1.5.2	Injection molding	18
2.1.5.3	Melt mixing method	18
2.1.5.4	Hand layup method	19
2.1.5.5	Solvent casting Method	19
2.1.6	Previous research on composites & packaging film	20
2.1.6.1	Incorporation of a reinforcing agent in Polymer composites	20
2.1.6.2	Incorporation of agro-waste in Polyethylene/Polypropylene composites	27
2.1.6.3	Incorporation of pretreated agro-waste in PE/PP composites	33
2.1.7	Response surface methodology study for optimization of inherent properties for packaging film	37
2171	Response surface methodology	37

Box-Behnken Design	38
Central composite design	39
Objectives	45
Polyethylene/polypropylene/alkali treated-wheat straw based packaging film	46-97
Introduction	46
Materials and Method	49
Materials	49
Alkali pre-treatment of wheat straw	49
Compositional analysis	50
Synthesis of polyethylene/polypropylene/alkali treated-wheat straw film	51
Experimental design and optimization for	53
polyethylene/polypropylene/alkali treated- wheat straw	
Characterization of native and pretreated-wheat straw	56
XRD analysis	56
FTIR analysis	56
Compositional analysis	56
•	56
1 0 0 1 11	57
<u> </u>	
· · · · · · · · · · · · · · · · · · ·	57
•	57
·	57
· · · · · · · · · · · · · · · · · · ·	57
	58
_	58
	58
<u>-</u>	59
•	60
	60
	60 60
· ·	62
	65
	66
· · · · · · · · · · · · · · · · · · ·	68
· · · · · · · · · · · · · · · · · · ·	68
at break and WVTR of PE/PP/Alkali treated-wheat straw	00
-	68
÷ •	70
Effect of process variables on Flongation at break (%)	74
	Central composite design Objectives Polyethylene/polypropylene/alkali treated-wheat straw based packaging film Introduction Materials and Method Materials Alkali pre-treatment of wheat straw Compositional analysis Synthesis of polyethylene/polypropylene/alkali treated-wheat straw film Experimental design and optimization for polyethylene/polypropylene/alkali treated- wheat straw based biocomposite film Characterization of native and pretreated-wheat straw XRD analysis FTIR analysis Compositional analysis SEM analysis Characterization of polyethylene/polypropylene/alkali treated-wheat straw bio-composite film SEM analysis TGA analysis TGA analysis TGA analysis Mechanical test Contact angle measurement WVP test Dart Impact test Optical characteristics test Results and discussion Characterization of native-WS and alkali treated-WS XRD analysis FTIR analysis Compositional analysis SEM analysis SEM analysis RSM and ANOVA analysis ANOVA and RSM analysis for tensile strength, Elongation at break and WVTR of PE/PP/Alkali treated-wheat straw biocomposite film Data adequacy check of the Model Effect of process variables on Tensile strength

3.3.2.1.4	Effect of process variables on WVTR	78
3.3.3	Optimization of the statistical model	82
3.3.4	Characterization of the optimized	82
	polyethylene/polypropylene/alkali treated-wheat straw bio-	
	composite film	
3.3.4.1	SEM analysis	82
3.3.4.2	FTIR analysis	84
3.3.4.3	XRD analysis	86
3.3.4.4	TGA analysis	88
3.3.4.5	Mechanical test	90
3.3.3.6	Contact angle	92
3.3.3.7	WVP test	93
3.3.3.8	Dart Impact test	94
3.3.3.9	Optical characteristics test	95
3.4	Conclusions	97
	Polyethylene/polypropylene/alkali treated-hemp fiber	98-147
	based packaging film	
4.1	Introduction	98
4.2	Materials and Method	101
4.2.1	Packaging Materials	101
4.2.2	Alkali pre-treatment of wheat straw	102
4.2.3	Compositional analysis	102
4. 2.4	Preparation of polyethylene/polypropylene/alkali treated-	104
4.2.5	hemp fiber film Experimental design and optimization for	104
4.2.3	polyethylene/polypropylene/alkali treated- hemp fiber based	104
	biocomposite film	
4.2.6	Characterization of native and pretreated-hemp fiber	107
4.2.6.1	XRD analysis	107
4.2.6.2	FTIR analysis	107
4.2.6.3	Compositional analysis	107
4.2.6.4	SEM analysis	108
4.2.7	Characterization of polyethylene/polypropylene/alkali	108
	treated-hemp fiber bio-composite film	
4.2.7.1	SEM analysis	108
4.2.7.2	FTIR analysis	108
4.2.7.3	XRD analysis	108
4.2.7.4	TGA analysis	109
4.2.7. 5	Tensile test	109
4.2.7.6	Contact angle measurement	109
4.2.7. 7	WVP test	109
4.2.7. 8	Dart Impact test	110
4.2.7. 9	Optical characteristics test	111
4.3	Results and discussion	111

4.3.1	Characterization of native-HF and alkali treated-HF	111
4.3.1.1	XRD analysis	111
4.3.1.2	FTIR analysis	113
4.3.1.3	Compositional analysis	115
4.3.1.4	SEM analysis	116
4.3.2	RSM and ANOVA analysis	118
4.3.2.1	ANOVA and RSM analysis for tensile strength, Elongation	118
	at break and WVTR of PE/PP/Alkali treated-hemp fiber	
	biocomposite film	
4.3.2.1.1	Data adequacy check of the Model	118
4.3.2.1.2	Effect of process variables on Tensile strength	120
4.3.2.1.3	Effect of process variables on Elongation at break (%)	124
4.3.2.1.4	Effect of process variables on WVTR	128
4.3.3	Optimization of the statistical model	132
4.3.4	Characterization of the optimized	132
	polyethylene/polypropylene/alkali treated-hemp fiber bio-	
	composite film	
4.3.4.1	SEM analysis	132
4.3.4.2	FTIR analysis	134
4.3.4.3	XRD analysis	136
4.3.4.4	TGA analysis	138
4.3.4.5	Mechanical test	140
4.3.3.6	Contact angle measurement	142
4.3.3.7	WVP test	143
4.3.3.8	Dart Impact test	144
4.3.3.9	Optical characteristics test	145
4.4	Conclusions	147
	Summary of thesis and future scope	148-149
	References	
	Publications	

List of Figures

Figure 1.1	Synthetic polymers waste generation data(Ritchie and Roser, 2018).	4
Figure 1.2 Figure 2.1	Classification of Agro-waste (Dhar et al., 2017). Generation of Box- Behnken Design (Ait-Amir, Pougnet, & El Hami, 2015).	6 38
Figure 2.2	Generation of Central composite design (Ait-Amir et al., 2015)	40
Figure 3.1	Schematic diagram for solvent casting method	52
Figure 3.2 Figure 3.3	XRD analyses for native-wheat straw and alkali treated- wheat straw. FTIR analyses for native-wheat straw and alkali treated- wheat straw.	62 64
Figure 3.4	SEM analyses for native and alkali treated- wheat straw (a) Native-WS (b) Alkali treated-WS.	67
Figure 3.5	Relationship between actual and predicted values of model (a) Tensile strength and (b) Elongation at break (%) (c) Water vapor transmission rate.	69
Figure 3.6	Three dimensional response surface and contour plots of tensile strength showing the effect of (a) and (b) polypropylene and polyethylene; (c) and (d) alkali treated-WS and polyethylene; (e) and (f) alkali treated-WS and polypropylene.	73
Figure 3.7	Three dimensional response surface and contour plots of elongation at break showing the effect of (a) and (b) polypropylene and polyethylene; (c) and (d) alkali treated-WS and polyethylene; (e) and (f) alkali treated-WS and polypropylene.	77
Figure 3.8	Three dimensional response surface and contour plots of water vapor transmission rate showing the effect of (a) and (b) polypropylene and polyethylene; (c) and (d) alkali treated-WS and polyethylene; (e) and (f) alkali treated-WS and polypropylene.	81
Figure 3.9	SEM analyses for all polymeric composite films (a) PE/PP film (b) PE/PP/native-WS (c) PE/PP/ alkali treated-WS composite films.	83
Figure 3.10	FTIR analyses for all polymeric composite films (a) PE/PP film (b) PE/PP/native-WS (c) PE/PP/ alkali treated-WS composite films.	85
Figure 3.11	XRD analyses for all polymeric composite films (a) PE/PP film (b) PE/PP/native-WS (c) PE/PP/ alkali treated-WS composite films.	87
Figure 3.12	TGA analyses for all polymeric composite films (a) PE/PP film (b) Real packaging (c) PE/PP/native-WS (d) PE/PP/ alkali treated-WS composite films.	89
Figure 3.13	Stress vs. strain curve for polymeric composite films (a) PE/PP film (b) Real packaging (c) real polyester packaging (d) PE/PP/native-WS (e) PE/PP/ alkali treated-WS composite films.	91
Figure 4.1 Figure 4.2 Figure 4.3	XRD analyses for native-HF and alkali treated- HF. FTIR analyses for native-HF and alkali treated- HF. SEM analyses for native-HF and alkali treated- hemp fiber (a) NHF	112 114 117

(b) Alkali treated-HF.

Figure 4.4	Relationship between actual and predicted values of model (a) Tensile strength and (b) Elongation at break (%) (c) Water vapor transmission rate.	119
Figure 4.5	Three dimensional response surface and contour plots of tensile strength showing the effect of (a) and (b) polypropylene and polyethylene; (c) and (d) alkali treated-HF and polypropylene.	123
Figure 4.6	Three dimensional response surface and contour plots of elongation at break showing the effect of (a) and (b) polypropylene and polyethylene; (c) and (d) alkali treated-HF and polyethylene; (e) and (f) alkali treated-HF and polypropylene.	127
Figure 4.7	Three dimensional response surface and contour plots of water vapor transmission rate showing the effect of (a) and (b) polypropylene and polyethylene; (c) and (d) alkali treated-HF and polyethylene; (e) and (f) alkali treated-HF and polypropylene.	131
Figure 4.8	SEM analyses for all polymeric composite films (a) PE/PP film (b) PE/PP/native-HF (c) PE/PP/ alkali treated-HF composite films.	133
Figure 4.9	FTIR analyses for all polymeric composite films (a) PE/PP film (b) PE/PP/NHF (c) PE/PP/ alkali treated-HF composite films.	135
Figure 4.10	XRD analyses for all polymeric composite films (a) PE/PP film (b) PE/PP/NHF (c) PE/PP/ alkali treated-HF composite films.	137
Figure 4.11	TGA analyses for all polymeric composite films (a) PE/PP film (b) Real packaging (c) PE/PP/NHF (d) PE/PP/ alkali treated-HF composite films.	139
Figure 4.12	Stress vs. strain curve for polymeric composite films (a) PE/PP film (b) Real PE packaging (c) real polyester packaging(d) PE/PP/NHF (e) PE/PP/ alkali treated-HF composite films.	141

List of Tables

Table 1.1	World plastics demands by different types of synthetic polymers in 2016(Europe, 2017)	3
Table 1.2	Chemical composition of some natural fibers.	7
Table 2.1	Literature review for the incorporation of a reinforcing agent in a	24
100010 201	polymer matrix for packaging application.	
Table 2.2	Literature review for native- agro-waste incorporated	30
	polyethylene and polypropylene matrix for packaging application.	
Table 2.3	Literature review for pre-treated agro-waste incorporated	35
	polyethylene and polypropylene matrix for packaging application.	
Table 2.4	Literature review for reinforcing agent in polymer matrix for	43
	packaging application using RSM.	
Table 3.1	Variables used in the experimental design represented with actual	55
	and coded values	
Table 3.2	Experimental design matrix for PE/PP/alkali treated-WS	55
	composite film with responses	
Table 3.3	Compositional analyses for native-WS and alkali treated-WS.	65
Table 3.4	ANOVA analysis for the tensile strength of PE/PP/alkali treated-	71
	WS from CCD model.	
Table 3.5	ANOVA analysis for elongation at break (%) of PE/PP/alkali	75
	treated-WS from CCD model.	
Table 3.6	ANOVA analysis for water vapor transmission rate of PE/PP/alkali	79
	treated-WS from CCD model.	
Table 3.7	Tensile stress, Yield strength, Elongation at break and Young	92
	modulus for all polymeric composite films.	
Table 3.8	Contact angle, Dart impact velocity, Dart impact failure weight,	96
	WVTR, WVP and light transmission rate for all polymeric	
	composite films.	
Table 4.1	Variables used in the experimental design represented with	106
	actual and coded values	
Table 4.2	Experimental design matrix for PE/PP/alkali treated-HF composite	106
	film with responses	
Table 4.3	Compositional analyses for native-WS and alkali treated-WS.	115
Table 4.4	ANOVA analysis for the tensile strength of PE/PP/alkali treated-	121
	HF from CCD model.	
Table 4.5	ANOVA analysis for elongation at break (%) of PE/PP/alkali	125
	treated-HF from CCD model.	
Table 4.6	ANOVA analysis for water vapor transmission rate of PE/PP/alkali	129
	treated-HF from CCD model.	
Table 4.7	Tensile stress, Yield strength, Elongation at break and Young	142
	modulus for all polymeric composite films.	
Table 4.8	Contact angle, Dart impact velocity, Dart impact failure weight,	146
	WVTR, WVP and light transmission rate for all polymeric	
	composite films	