International Journal Of Engineering Research And Development
e- ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 17, Issue 4 (Jul. – Aug. 2021), PP. 39-50

Production, Characterization and Optimization of Biodegradable Plastic from Corn starch and Sugarcane Bagasse

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ABSTRACT: *There is an increasing need for biodegradable plastics because of they are environmentally friendly and can replace petroleum-based non-degradable plastics which pollute the environment. Recently huge efforts are exerted in substitution of petroleum based polymers by biodegradable ecofriendly composites because of the toxic effect of the synthetic polymers. Petroleum base polymers are not sustainable as they depend on depleting fossils. This work studies the effect of Bagasse (sugarcane byproduct) fiber weight fraction on starch based composite.*

This study also investigated the potentials of starch and sugar cane cellulose fiber for bioplastic productions. The effect of oven drying and starch-cellulose fiber ratio was also studied. The experimental design was employed using design expert 6.0.8 two factor three level central composite designs (CCD) including five replicates at the center point of optimization study requiring 13 experiments on the 3 responses were analyzed namely tensile strength, water absorption and elongation at break.

Results have shown that the addition of cellulose fiber (5 wt%, 10 wt% and 15 wt%) to selected gram of corn starch(5g), the value obtained were for tensile strength (13.27MPa, 24.45MPa and 22.18MPa, respectively), water absorption (36.90, 23.6 and 24.01% respectively) and elongation at break (20.25, 5.268 and 9.58% respectively), these values are the averages of replication treatment.

From the analysis of experimental results the maximum and minimum value of tensile strength (26.81 and 11.55MPa), water absorption (39.02% and 20.45%) and elongation at break (25.99% and 4.32%) was obtained respectively. Starch-derived bioplastic reinforced with cellulose fiber at the optimal point of the responses namely tensile strength, water absorption and elongation at break, which are biodegradable, have been prepared and characterized for FTIR, compound microscope, Transparency, solubility, and density. Results obtained under optimal condition were found that Transparency of reinforced bioplastic reduced by 5%with respect to the control. Also its solubility decreased from (14.78% to 10.17%) while density was increased from (1.059g/ml to1.069g/ml). Evidence of the existence of strong interactions between the starch matrix and the cellulose fibers was revealed from detailed Fourier Transform Infra-red (FTIR) and compound microscopic evaluation.

KEYWORDS: *Bioplastic, Starch, Sugarcane fiber, tensile strength, water absorption, elongation at break*

Date of Submission: 26-06-2021 Date of Acceptance: 08-07-2021

I. INTRODUCTION

The word polymer is derived from the Greek, polyand merosmeaning manyand parts respectively. The long chains of atoms which comprise polymers and the bonds within and between the chains determine plastics properties. Polymers alone cannot be plastics. Plastics are polymers or macromolecules which have been modified with additives and mechanically strong plastic structure that adopt a dimensionally stable form. Almost 35 million tones of synthetic polymers are produced annually in the USA. and growth is expected as long as petroleum and other feed stocks last and consumer demand continues (Mo,X.Z. 2010). In the last 60 years, the synthetic polymers have experienced a progressive growth, constituting an important area in the polymer science. During this period these materials have invaded almost all human activities. This fact is due to their low cost, repeatability at high velocity of production and its durability, and high resistance to the physical aging and bacteriological attacks. Nowadays, plastic utilization is increasing rapidly. This is because plastics can be used in many applications such as packaging, construction and automobile parts, etc. The need for such large quantities of conventional plastics and their dominance over other materials is due to their excellent “long life” properties. These properties include resistance to enzymatic reactions. Biodegradable polymers, specifically from renewable resources, are being examined for replacement of synthetic plastics.

The resources used in the production of renewable biopolymers are continually replenished which becomes advantageous over traditional plastics for sustainability. Typical commercial biopolymers are polylactic acid (PLA), polyhydroxyalkanoates (PHA), starches, and bagasse. Some applications for PHAs range from stiff packaging to flexible coatings (B.P. Mooney, 2009). PLA can be used for flexible packaging or drinking cups as well as similar applications to polypropylene (PP) and polystyrene (PS) (Cao *et al.*, 2006). Applications for starches reside mainly with food packaging (Janssen and L. Moscicki, 2009). Where starch products are known for their highly hydrophilic nature, current applications are limited. When comparing the mechanical properties of synthetic and biodegradable plastics, there is a wide range of values for the strength of both classes of materials, but generally synthetic plastics are stronger than biodegradable plastics (Abdul Khalil et al, 2012). The degradation period of synthetic plastics may last up to 450 years in a landfill whereas some biodegradable polymers, starch and bagasse composites, may degrade within a few months (Fengel*et al.*, 1984).

Basically the technique used to manufacture synthetic plastics can be used for the manufacturing of biodegradable materials. The solvent casting process of thermoplastic solution is the most utilized technologies at laboratory scale for the plastic manufacturing. Some researchers have reported that these processes can be utilized individually or together for the development of new thermoplastic products which can be used like biodegradable materials for the production of diverse degradable materials with similar or better characteristics than those of commercial plastics, although, with the advantage of decreasing the adverse effect of waste disposal on the global environment (Carr and Cunninghan, 1989). In this research, environmental friendly plastic was produced using the addition of cellulose fiber as a reinforcement material in corn starch matrix and glycerol as a plasticizer in the process of solvent cast method.

II. MATERIAL AND METHODS

The experimental procedure for the development of bioplastic is depicted in the Figure 2.1 below. Detailed description of the process is given in the text that follows.

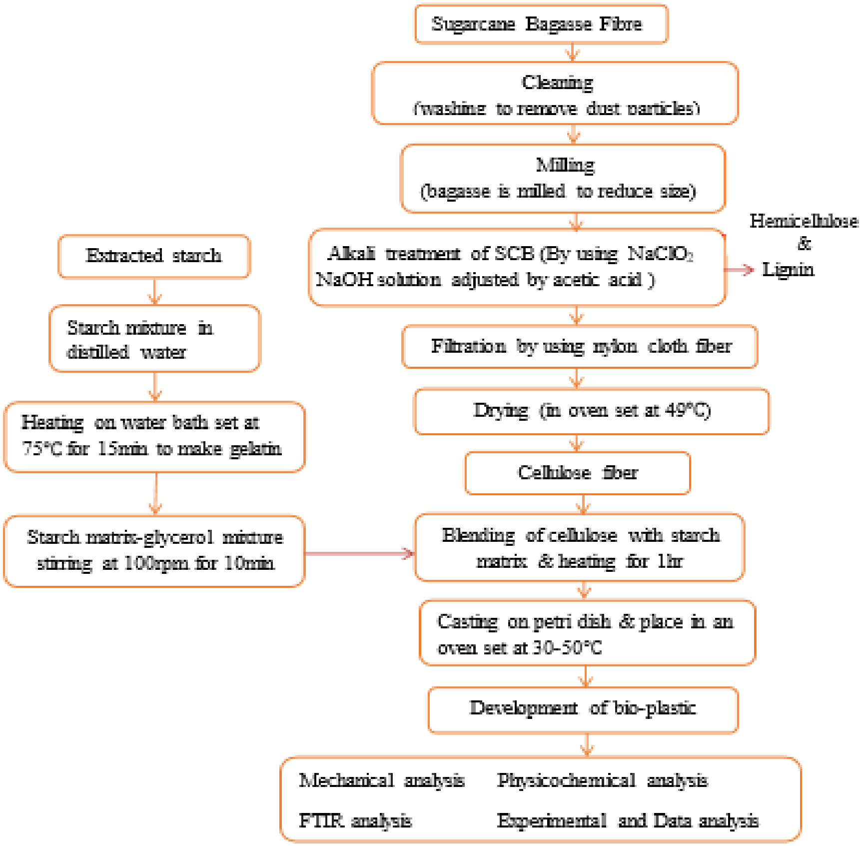


Figure 2.1: Experimental procedure for production of bioplastic from corn starch and cellulose fiber

II.I Methods

II.I.I Development of bioplastic from corn starch and cellulose fiber

Location: The experimental studies were conducted at Addis Ababa University institute of Technology (AAIT), Leather Industry Development Institute and Addis Ababa University College of natural science.

Materials: The raw materials used for this study were sugar cane bagasse fiber -it was kindly supplied by Fincha Sugar Factory located in horoguduru wollega zone, glycerol (chemical formula C_3H_5 $(OH)_3$, Batch G120313) was purchased from Micron PLC and Corn starch was used as a matrix were prepared in laboratory.

Equipments: The equipments used during the experimentations includes Wiley mill, sieve, strip road, Silica crucible, desiccators, digital weighing balance, weight bottle, stopper, tong, Erlenmeyer flask, water bath, vacuum suction, weighed sintered glass crucible, what-man filter paper, measuring cylinder, round bottom flask, cellulose extraction thimble, beaker, scissor, dryer, glove, mask, thermometer, stirring rod, air circulated oven.
Chemicals: Chemicals used in the production of bioplastic were glycerol, sodium chlorite ($NaClO_2$), sodium hydroxide (NaOH), glacial acetic acid and distilled water was the chemicals those used in development process.

II.I.I.I Extraction of starch from corn (maize)

Extraction of maize starch was done as described by White *et al.*, (1990) modified by Krieger *et al.*, (1997). First, we clean the shelled corn shipments to ensure that they are free from dust and foreign bodies. Once clean, the corn is soaked in water, at 50˚C for between 24 hours, during which time it doubles in size. As the corn swells and softens, the mildly acidic steep water starts to loosen the gluten bonds with the corn, and to release the starch. The corn is coarsely milled in attrition mills to separate the germ from the rest of the components. The remaining slurry then leaves the separation step for fine grinding. After the fine grinding, releases the starch and gluten from the fibre, the slurry flows over fixed concave screens which catch the fibre but allow the starch and gluten to pass through. The starch, gluten suspension is sent to the starch separators. The starch, gluten suspension passes through a centrifuge where the gluten, which is less dense than starch, is easily spun out. The process is shown in Figure 2.2.

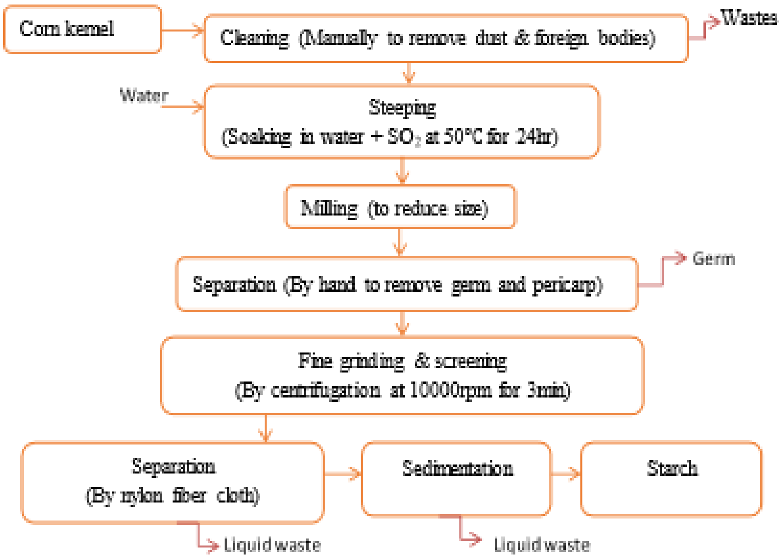


Figure 2.2: Extraction of starch process flow diagram

II.I.I.2 Delignification and isolation of cellulose from sugarcane bagasse fibre

In this work the particle size was selected as determined from the literature, the dried, milled and screened by 80µm sieve size (100g of SCB) was first bleached with 0.7% (w/v) sodium chlorite ($NaClO_2$) solution (fibre to liquor ratio of 1: 50) at pH4, adjusted by % acetic acid that was used to acidify $NaClO_2$ solution. The fibre was boiled in the solution for 2hours on water bath set at $75^{O}C$ to remove lignin completely and hemicellulose partially. The bleaching process was repeated for four to five times until fibre become white and then filtered. The holocellulose thus obtained was boiled with 250 ml 17.5% (w/v) sodium hydroxide solution for 5 h to remove the hemicelluloses.After being filtered, the residue was washed for several times with distilled water. At the end of extraction the insoluble residue (cellulose) was collected by filtration and it was oven dried.

II.I.I.3 Synthesis of bioplastic from corn starch and cellulose fiber

The sample was prepared by the procedure adapted from the method described by (Eraricar S.et al., 2009). A film forming dispersion was prepared by mixing the starch (10g) and distilled water (200ml). The dispersion was stirred manually on magnetic strier set at 70-80°C for 15 min while stirring at the same rate until it become gelatinized. Then glycerol (3.6ml) was added and stirred for 10 min. Cellulose fibre was then added at 0.00, 0.50, 1.00 and 1.5g (dry basis) based on a starch weight basis. Each mixture was stirred for homogeneity and to make the gelatin very strong and then allowed to cool to 75 °C before being cast on a non-stick tray. Then the solution, while still hot, the mixture was transferred into petri dishes using weight balance to keep its uniformity (Lafargue et al. 2007). Dishes will place in an oven set at 50°C, $40^{O}C$ and $30^{O}C$ until the film was dry. Subsequently the dishes are removed from the oven and the films was peeled off, stored at room temperature in polyethylene bag for further analysis. The analysis variables are drying temperature and fiber content in blends with starch. The pictures of developed bioplastic shown in figure 2.3.

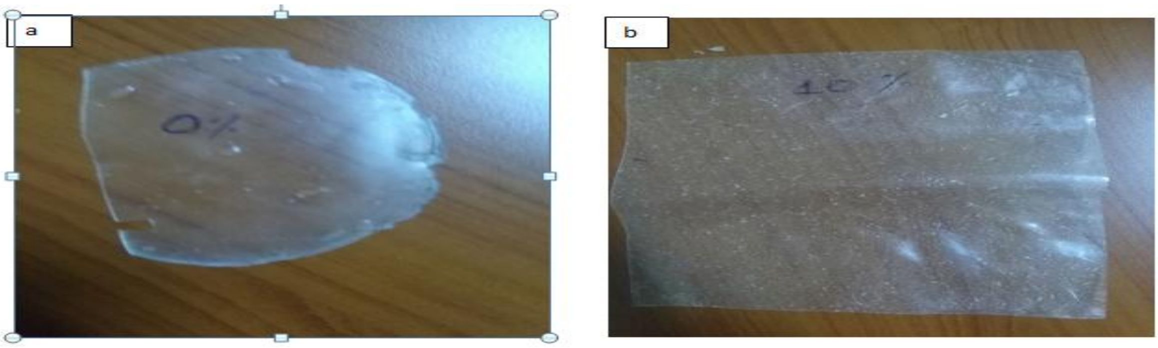


Figure 2.3: Pictures of developed bioplastic with (a) 0% starch matrix (b) optimal cellulose fibre (10% wt)

II.II Evaluation of mechanical properties of developed bioplastic

II.II.I Tensile strength and elongation at break

Tensile strength and elongation at break are the most important mechanical properties of the packaging bio-plastic. So that it is favoured to characterize the prepared bio-films with these parameters

$$\text{Tensile strength at yield (MPa)} = \frac{\text{Force(N)}}{\text{Area(width in mm x thickness in mm)}}$$

$$\text{\% Elongation} = \frac{\text{Increase in length}}{\text{Original length}} \text{x100}$$

II.III Characterization of physicochemical properties of produced bioplastic

For every physical testing, before starting the sample was conditioned for 48hr in a specified temperature and humidity. For this we use standard test method (ISO 2418:2005 and ISO2419:2005, Sampling & Conditioning). The properties of Water absorption, Water solubility, Density of developed bioplastic, Transparency of produced bioplastic, FTIR analysis of bioplastic was analysed.

II.IV Experimental design and data analysis

Response surface methodology (RSM) will be adopted in the design of experimental combinations. The main advantage of RSM is to reduce the number of experimental runs needed to provide sufficient information for statistically acceptable results. A three variable (three levels of each) central composite experimental design was employed (Montogomery, 2001). The ratio of cellulose fiber concentrations has strong impact on the final performance of prepared bioplastic.

The first task before conducting the experiments was selection of potential parameters to be varied. The two main factors selected in this study were oven-drying temperature, concentration cellulose fiber. The level of the selected factors is determined from the literature research and is presented in table 2.1. The experiment performed as a completely randomized design with two main factors at three levels and three response variables. The processing variables (concentration of cellulose fiber and drying temperature (^{o}C) were optimized using RSM to study their effect on the functional properties of prepared plastics. The responses that were considered during the optimization of the Processing variables are solubility, water absorption, tensile strength and elongation at break. The prepared bioplastics physical (solubility and water solubility) and mechanical (TS and EB) properties, and the effect of independent variables on the prepared bio-films were checked.

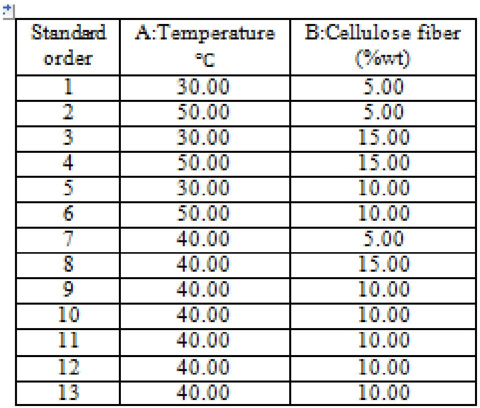
Data analysis has performed by DESIGN EXPERT$^{®}$ 6.0.8 software using Response surface methodology design method and randomizes the runs. Randomization ensures that the conditions in one run neither depend on the conditions of the previous runs nor predict the conditions in the subsequent runs. Randomization is essential for drawing conclusions from the experiment, in correct, unambiguous and defensible manner.

This design of the experiment helps us to differentiate the significance of the main and the interaction factors. This program software also used to develop the mathematical model that will describe the effects of the main and interaction factors on the response. The proposed RSM design required 13 runs. Detail of the experimental runs with the set of input parameters that were conducted are given in Table 2.2

Table 2.1: Levels of independent variables for the development of bioplastic based on central composite design

Independent Variable	Units	Coded symbol	Coded Levels		
			-1	0	+1
Drying Temperature	°C	A	30	40	50
Cellulose fiber to Starch	w/w%	B	5	10	15

Table 2.2 Two factors, three levels face centered cube design with five center point formulation

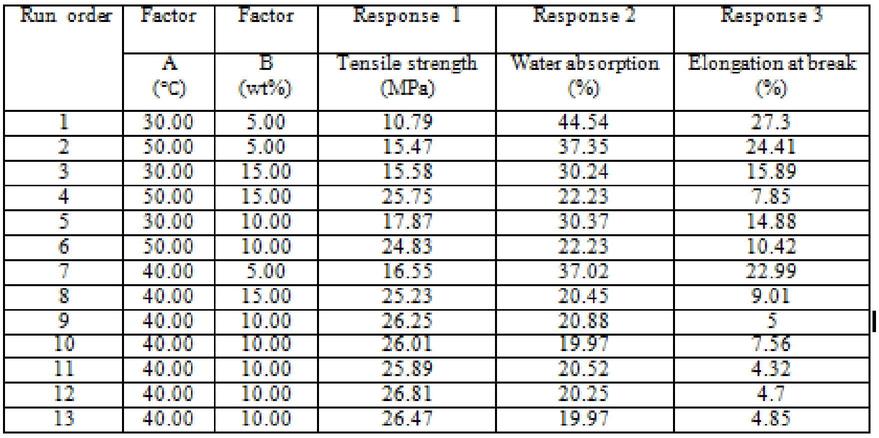


Standard order	A:Temperature °C	B:Cellulose fiber (%wt)
1	30.00	5.00
2	50.00	5.00
3	30.00	15.00
4	50.00	15.00
5	30.00	10.00
6	50.00	10.00
7	40.00	5.00
8	40.00	15.00
9	40.00	10.00
10	40.00	10.00
11	40.00	10.00
12	40.00	10.00
13	40.00	10.00

III. RESULTS AND DISCUSSION

The determination of mechanical properties involves not only scientific, but also technological and practical aspects (Gontard , 1993). Thus, the mechanical properties of the films were studied to determine the values of important parameters such as tensile strength (TS) and percent of elongation at break (E). The value of tensile strength, water absorption and Elongation at break for Bio-plastic at a level of 2 factors is depicted in table 3.1

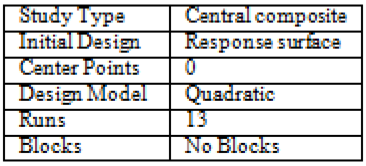
Table 3.1Experimental design and responses



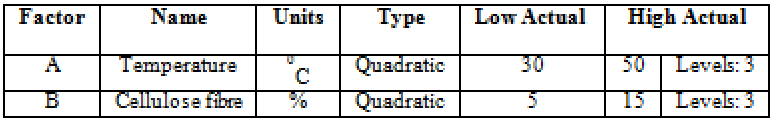
Run order	Factor	Factor	Response 1	Response 2	Response 3
	A (°C)	B (wt%)	Tensile strength (MPa)	Water absorption (%)	Elongation at break (%)
1	30.00	5.00	10.79	44.54	27.3
2	50.00	5.00	15.47	37.35	24.41
3	30.00	15.00	15.58	30.24	15.89
4	50.00	15.00	25.75	22.23	7.85
5	30.00	10.00	17.87	30.37	14.88
6	50.00	10.00	24.83	22.23	10.42
7	40.00	5.00	16.55	37.02	22.99
8	40.00	15.00	25.23	20.45	9.01
9	40.00	10.00	26.25	20.88	5
10	40.00	10.00	26.01	19.97	7.56
11	40.00	10.00	25.89	20.52	4.32
12	40.00	10.00	26.81	20.25	4.7
13	40.00	10.00	26.47	19.97	4.85

The resulting data, Table 3.1 were analyzed using Design expert® 6.0.8 software to determine the effects of oven-drying temperature and concentration of cellulose fiber. The dependent variables used as a response parameter were the tensile strength, water absorption and elongation at break. All experiments were carried out in a randomized order to minimize the effect of unexpected variability in the observed response due to extraneous factors. And the design summary for the experiment is shown in table 3.2.

Table 3.2 Design summery



Study Type	Central composite
Initial Design	Response surface
Center Points	0
Design Model	Quadratic
Runs	13
Blocks	No Blocks



Factor	Name	Units	Type	Low Actual	High Actual	
A	Temperature	°C	Quadratic	30	50	Levels: 3
B	Cellulose fibre	%	Quadratic	5	15	Levels: 3

Development of regression model equation

Table 3.1 summarizes the result obtained with the experimental design which was aimed at determining the condition that favors maximum tensile strength reduce water absorption and increase elongation at break. A quadratic model equation shown below was fitted to the data model for predicting responses; Tensile strength, Water absorption and elongation at break respectively. F ratio is calculated for 95% of level of confidence.

III.I Tensile strength of produced bioplastic

Equation in Terms of Coded Factors:

$\text{Tensile Strength} = +26.16 + 3.63 * A + 3.96 * B - 4.48 * A^2 - 4.94 * B^2 + 1.3 * A * B$

Equation in Terms of Actual Factors:

$\text{Tensile strength} = -76.77115 + 3.67341*A + 3.64608*B - 44805*A^2 - 0.19762*B^2 + 0.027450*A*B$

Where: A = Oven-drying temperature, B= Cellulose fiber

III.II Water absorption of bioplastic

Equation in Terms of Coded Factors:

$\text{Water Absorption} = +21.78 - 3.72 * A - 6.33 * B + 6.35 * A^2 + 4.29 * B^2 - 0.70 * A * B$

Equation in Terms of Actual Factors:

$\text{Water Absorption} = +21.78379 - 3.72333*A - 6.33167*B + 6.35172*A^2 + 4.28672*B^2 - 0.7050*A*B$

Where: A = Oven-drying temperature, B= Cellulose fiber

III.III Elongation at break for bio-plastic

Equation in Terms of Coded Factors:

$\text{Elongation at break} = +5.91 - 2.57 * A - 7.00 * B + 5.20 * A^2 + 8.55 * B^2 - 1.28 * A * B$

Equation in Terms of Actual Factors:

$\text{Elongation at break} = +137.2826 - 4.1582*A - 7.2142*B + 0.0519*A^2 + 0.3418*B^2 - 0.0255*A*B$

Where: A = Oven-drying temperature, B= Cellulose fiber

III.IV Effect of process variables

The effect of each independent variable on the physical and mechanical properties of the bio films was investigated by keeping other variables constant. Moreover, from the model equation, the coefficients of the independent variable show the effect of each independent variable on physical as well as mechanical properties.

III.IV.I Effect of individual process variables

III.IV.I.1 Effect of drying temperature on tensile strength of bio plastic

The effect of drying temperature on Tensile Strength of bio-plastic was shown in Figure 3.1 below. From the graph it can be observed that as temperature start to increase from low level coded (-1) up to center point coded (0) tensile strength also increases, but beyond center point the tensile strength shows slight decreasing and become parabolic. It can be caused by the influence of higher temperatures, can cause intermolecular bonds in starch chains becoming weaker. The hydrogen bonds between amylose chains undergo termination of the bond.

III.IV.I.2 Effect of cellulose fiber concentration on tensile strength

As depicted in figure 3.2 below the effect of Cellulose fiber to starch ratio on tensile strength can be observed that as the ratio of Cellulose fiber increases the response of tensile strength increases up to center point coded (0) and beyond to some extent and become decreases as cellulose fiber increases further up to higher level coded(+1). Probably this effect is due to an interaction of the fibre with the matrix, decreasing the molecular mobility and resulting in more rigid and less flexible materials (Wu *et al.*, 2003). The fibre content in the matrix of synthetic or biological polymers increased the values of elasticity modulus and tensile strength of bioplastic; and decreased the values of elongation at fracture (Oskman *et al.*, 2003).

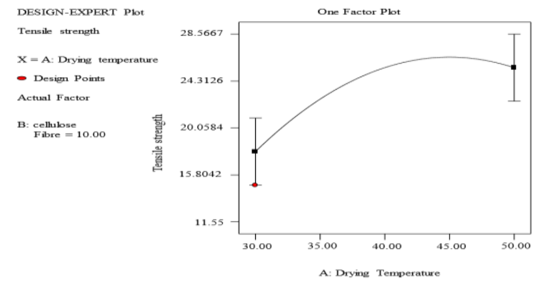


Figure 3.1 Effect oven drying temperature on tensile strength of developed bio-plastic

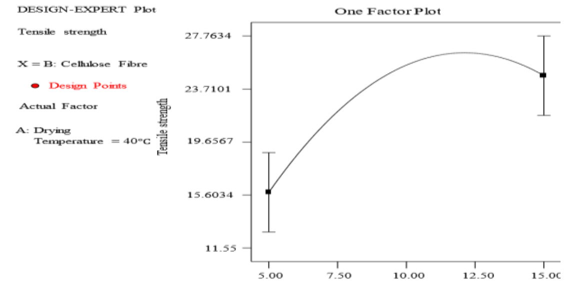


Figure 3.2 Effect of cellulose fiber concentration on tensile strength of developed bioplastic

III.IV.I.3 Effect of drying temperature on water absorption of bioplastic.

The effect of drying temperature on water absorption of bio-plastic was shown in figure 3.3. As shown in the figure, the lowest water absorption was observed at center point coded (0) or at 40°C. As we move from lowest coded level(-1) to center point the water absorption decreases, and as drying temperature increases from center point to higher level coded(+1) water absorption start to increases this was in agreement with some literature results.it was found out that in the work of (Ahmed*et al.*, 2014)

III.IV.I.4 Effect of cellulose fiber on water absorption of bioplastic

Sensitivity of the composites (bioplastics) to water absorption from the environment may be one of the most important parameters to consider for some applications, as water absorption affects the properties of starch-based composites (Müller *et al.* 2009). As shown from the figure 4.4 bellow the water absorption decreased when the percentage of Cellulose fiber increased from lowest level to center point coded (0) or up to 10% of Sugarcane bagasse cellulose in the bio-composites, as we move from center point to higher level water absorption starts to increase slightly and become a show parabolic line.

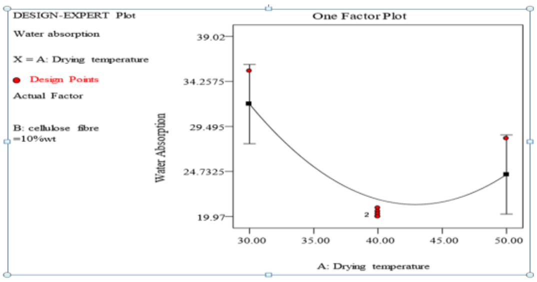


Figure 3.3 Effect of oven drying temperature on water absorption of developed bio-plastic

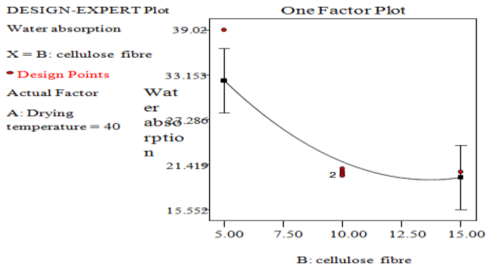


Figure 3.4 Effect of cellulose fiber on water absorption of bioplastic

III.IV.I.5 Effect of drying temperature on elongation at break of bio-plastic

From figure 3.5 it illustrated that increasing oven drying temperature of the bio - plastic solution causes the value of elongation at break decreases until it reach the center point. Which was due to increasing the tensile strength of bio-plastic as well as increasing drying temperature from lower level coded (-1) up to center point coded(0). The result of elongation at break decreases with increasing the temperature and as shown from the figure as drying temperature increases to high level coded (+1) elongation at break start to increases smoothly. It is because the heat that is given causes an increase in the kinetic energy of the molecules in which the molecules vibrate and create a free volume to allow larger molecular chains rotation (Patrycja, Wojciechowska, 2012)

III.IV.I.6 Effect of cellulose fiber on elongation at break of bioplastic

The effect of cellulose fibre content on elongation at break of developed bio-plastic was shown in figure 3.6 as shown from the figure below increasing fiber content from low level coded (-1)up to center point coded (0) decreases response elongation at break up to cellulose fibre content reaches 10% and elongation at break become increasing as cellulose fibre content further increases beyond 10% or center point.

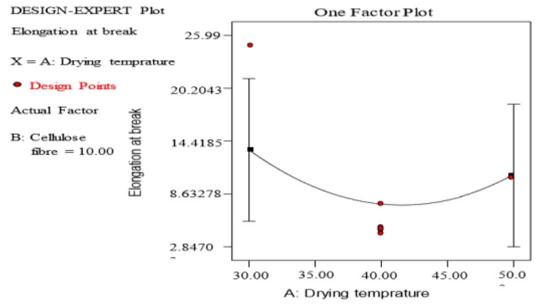


Figure 3.5 Effect oven drying temperature on elongation at break of bio-plastic

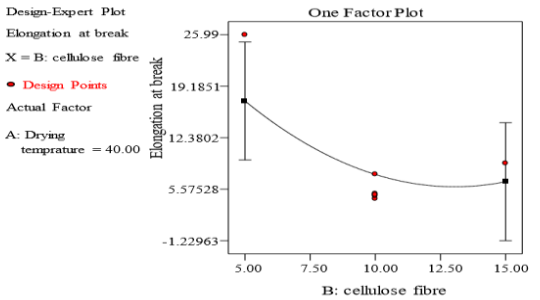


Figure 3.6 Effect of cellulose fiber on elongation at break of bioplastic

III.IV.I.7 Effects of interactive parameters between process variables on tensile strength, water absorption and elongation at break

Figure 3.7 to 3.12 shows the effect of the interaction of drying temperature and starch-cellulose fiber ratio where the maximum values of tensile strength (26.81 MPa) were at drying temperature of 40℃ and cellulose fibre (10 wt%) concentration. However, further increase in oven drying temperature above 40℃ and the increase of fibre content above 10 % in the blend smoothly increase the values of water absorption and elongation at break. Low drying temperature values (30°C) and low contents of cellulose fibre (5%) showed the minimum tensile strength values (10.79 MPa) and at oven drying temperature (40°C) and cellulose fibre (10%) shows maximum tensile strength (see figure 3.10 below). In general the values of tensile strength were favored at the center values of drying temperature and cellulose fiber. The increment of oven drying temperature values decreased drastically both water absorption and elongation at break (see figure 3.12 and 3.13 below) for water absorption and elongation at break respectively. Thus, high contents of cellulose fiber originated flexible films, however, with a low resistance to the tension as shown in assay (4) number (drying temperature 50°Cand cellulose fiber 15%) but better than low level. In a general way the values of Water absorption and elongation at break were increased with an increasing of and cellulose fibre and also at high values of drying temperature and cellulose fibre the value of both responses start to increase. Thus, the values of both water absorption and elongation at break were favored at 40℃ and 10% of cellulose fibre (CF) (see figure 3.12 and 3.13) below of 3D and counter surface plot. The incorporation of cellulose fibre acts as reinforcement in thermoplastic materials (Averous*et al*., 2001). This evidence was demonstrated in assay where the absence of sugarcane bagasse cellulose fibre decreased the value of tensile strength.

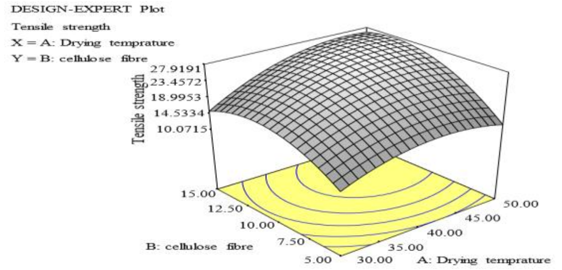


Figure 3.7Effects of drying temperature and cellulose fibre interactive on tensile strength, water absorption and elongation at break.

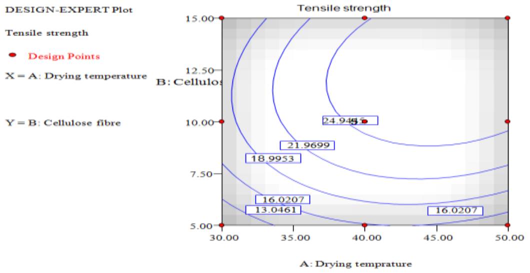


Figure 3.8 Effect of drying temperature and cellulose fibre on tensile strengthcontour plot bioplastic

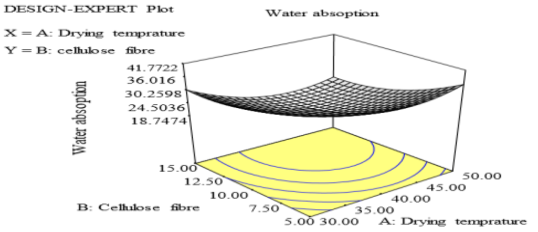


Figure 3.9 Interactive effects of drying temperature and cellulose fibre on water absorption of developed bioplastic

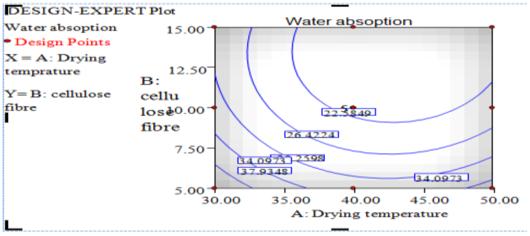


Figure3.10 Contour effect of drying temperature and cellulose fibre on water absorption of bioplastic

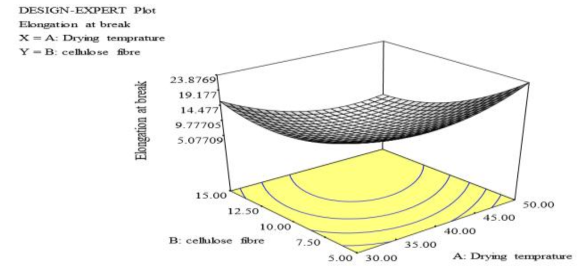


Figure 3.11 Interactive effects of drying temperature and cellulose fibre on elongation at break of bioplastic

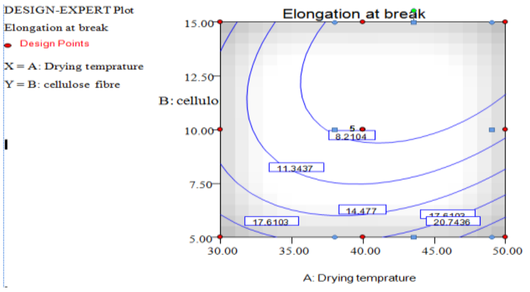


Figure 3.12 Effect of drying temperature and cellulose fibre on elongation at break contour

III.V Optimization of process factors

The broad optimization objective is the maximization of quality and minimizing of oven drying costs. RSM (Response Surface Methodology) is a collection of statistical and mathematical techniques used for developing, improving, and optimizing processes in which a response of interest is influenced by several variables and the objective is to optimize the response. Optimization analyses were conducted on the data from the Central Composite Design (CCD) to relate drying temperature and sugar cane bagasse cellulose fibre concentration to Tensile strength, water absorption and elongation at break of developed specimen. The numerical optimization was generated by design expert 6.0.8 software and elucidated in a table 3.3 below as a function of two factors drying temperature and sugar cane bagasse cellulose fibre. An optimal processing conditions of the bioplastic developed from corn starch and cellulose fibre was selected for further characterization based cellulose fibre and oven drying temperature setting in the range and as well as maximizing the tensile strength and minimizing water absorption and elongation at break of the sample (see table 3.3below). Therefore, considering those parameters the value obtained from optimum experimental for drying temperature (40.85℃), cellulose fibre (12.20%), tensile strength (27.2175),water absorption(18.3257%) and Elongation at break (4.25203%) were obtained with desirability of 1.00

Table 3.3 Optimization constraint for developed bioplastic

Constraints Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
Drying temperature	Is in the range	30	50	1	1	1
Cellulose fiber	Is in the range	5	15	1	1	1
Tensile strength	Maximize	10.79	26.81	1	1	1
Water absorption	Minimize	19.97	44.54	1	1	1
Elongation at break	Minimize	4.32	27.34	1	1	1

III.VI Physicochemical characterization of developed bioplastic from starch-cellulose based fiber

III.VI.1 Compound microscopy

In Fig 3.13 the compound micrographs of bio-plastics prepared with particle sizes of 80µm (a) unfilled starch matrix of control and (b) reinforced bioplastic are shown. The biocomposite samples observed in Fig.3.13 correspond to thermoplastic material prepared unfilled matrix without reinforcing cellulose particles, and the samples shown in (b) prepared with a treated sugarcane bagasse fiber (cellulose) amount of 10% contained. As can be observed in reinforced bioplastic, an even distribution of cellulose particles in the thermoplastic starch matrix is clearly evident due to the obtained transparency. Moreover, Fig.3.13b shows the compatibility of the reinforcing material with the matrix and the organization of the cellulose fiber in the bioplastic

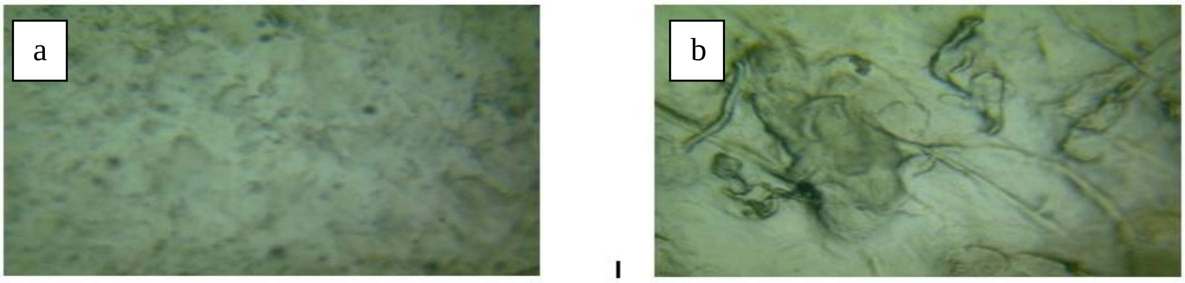


Figure 3.13 Micrographs of bioplastic (a) Unfilled starch matrix (b) Filled with 10% treated fiber.

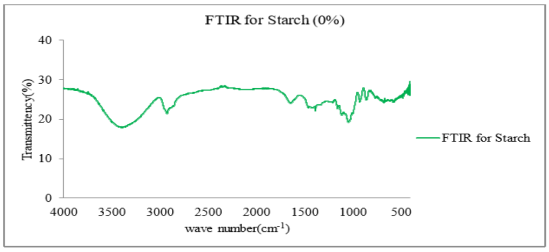
III.VI.2 FTIR spectroscopy analysis

The FTIR spectra of only starch-based bioplastic or a control (100% starch) and starch-cellulose fibre composites (10% cellulose content) were examined with respect to characterizing the chemical bonds between fibers and starch. The major observed peaks could be identified as the functional groups of starch and fiber. However, there were some slight changes in band positions and intensities. It is known that if two polymers are compatible, a distinct interaction (hydrogen bonding or dipole interaction) exists between the chains of one polymer and those of the other, causing the FTIR spectra of composites to change. It is evident in Figure 3.14 that characteristic peaks appeared at 3200 cm^{-1} to 3500 cm^{-1}.

Table 3.4 Signal Assignments of Functional groups identified by Fourier transform- Infrared spectroscopy analysis of bioplastic

Wave number (cm^{-1})	Functional groups
1005-897	C-O-H stretching
1150-1005	C-C stretching
1235-1150	C-O-C stretching of Easter
1734-1631	Bounded water
3000-2826	C-H stretches
3600-3450	-OH stretching

The FTIR spectra of bio-composites with reinforced material (sugar cane bagasse cellulose fibre) content amounts (10%) and organized by particle sizes of 80μm which is keeping it at constant is depicted in Figure.3.15. In this case, different signal patterns are observed from bio-composites prepared (Fig. 3.15) as a result of their different chemical composition due to addition of fiber, the following changes in the intensity of some signals. The amount of adsorbed water seemed to have a small increase in the bio-composite that had 10% fibre content. However, this may be only an optical effect caused by the decrease of the adjacent carbonyl band (1720 cm^{-1}). In contrast, the signal at 1099 cm^{-1} for control decreased to 1050cm^{-1} when 10% of cellulose fibre was added to the starch. Although the carbonyl signal (1720 cm^{-1}) of bio-composites prepared with particles of 80μm (Fig. 3.15) was more intense than that of the control sample bio-plastic (Fig.3.14).



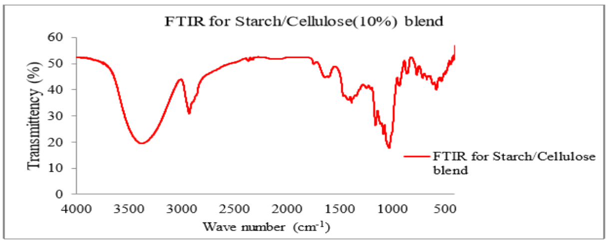


Figure 3.14 FTIR result of starch-based bioplastic **Figure 3.15 FTIR result of starch-cellulose bio-plastic**

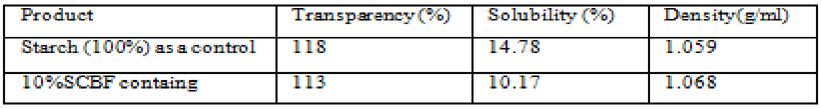
III.VI.3 Transparency of developed bioplastic

The percentage of transmittance of corn starch film at a wavelength of 600 nm and containing optimum cellulose fiber (CF) (10% concentration) prepared by solvent casting process. The results showed (see Table 3.5) that the films were off white in color but highly translucent. Addition of cellulose increased film cloudiness for starch-based films. This was due to the cellulose being cloudier than the corn starch so the transparency decreases of 118% for starch to 113% for 10% cellulose containing bio-plastic (see Table 3.5).

III.VI.4 Solubility and density of developed bioplastic

Solubility of starch-based films: Starch, being a hydrophilic polymer, shows high affinity towards water. Hence, upon hydration, starch-films absorb water and swell. The swelling behavior of the plasticized starch based film formed with cellulose fibreis shown in Table 3.5. Based on the results it can be recommended that films having a low solubility are favorable for the packaging purpose. Density of film developed from 100% starch and 10% CF containing was 1.059 g/ml and 1.068g/ml, respectively (see Table 3.5), there was an increment in density in the case of CF, this is may be due to the addition of 10% of cellulose fibre.

Table 3.5 Experimental result data for measuring bioplastic transparency, solubility and density



Product	Transparency (%)	Solubility (%)	Density(g/ml)
Starch (100%) as a control	118	14.78	1.059
10%SCBF containg	113	10.17	1.068

IV. CONCLUSION AND RECOMMENDATION

IV.I CONCLUSION

In this research, the development of bioplastics from corn starch and cellulose fibre from sugar cane was investigated. Sugar cane bagasse fibers with an average diameter of 80μm derived from bleached or treated pulp, slightly decreased the moisture content of starch films, but doubled the tensile strength. These tensile test results are slightly higher than those obtained by wheat grass cellulose fibre composites but similar to those of flax cellulose crystals (Cao et al. 2008). As well as, in this work the strength of the cellulose fibre composite decreased at fibre loadings above 10 wt%. This may be caused by fibre agglomeration and entanglement due to the cellulose fibre having a high aspect ratio. The films formed with the mix of starch and saponins were highly flexible and resembled plastic films.

The effect of cellulose fibre to starch ratio and oven drying temperature on the tensile strength, water absorption and elongation at break were studied. The output of the experiments conducted has been analyzed by design expert 6.0.8 of three levels and two factor central composite designs and response surface methodology was employed. In the development of bioplastic the three responses were significantly depend on starch-cellulose fibre ratio and oven drying temperature. Generally, as processing condition (cellulose fibre and oven drying temperature) increase from low level to center point tensile strength increases, but, was slightly decreased at some interval as both processing conditions increased from the center to the highest level. In terms of water absorption the changed level of drying temperature and cellulose fibre ratio results water absorption decreased as drying temperature increased from low level to vicinity of middle level and increases as moved to a higher level. In terms of elongation at break of the specimen the increase oven drying temperature causes the value of elongation at break decreases until it reaches center point. As well as further increasing of drying temperature from center point the result of elongation at break increases smoothly. In both process conditions elongation at break decreases from low level to center point and increase slightly starting from the center point to high level. But, the development of bioplastic was very sensitive to oven drying temperature followed by cellulose fibre ratio in all three responses that means tensile strength, water absorption and elongation at break were mainly affected by oven drying temperature than cellulose fibre. From the design software employed the maximum tensile strength of 26.81 MPa, water absorption of 20.52% and elongation at break of 4.32% were obtained at optimal value of the processing condition. Using numerical optimization of design expert 6.0.8 for development of bioplastic from cellulose fibre and cornstarch at operating condition for drying temperature(44.68^{O}C), cellulose fibre (13.99%) determined for developing bioplastic by solvent cast process.

FTIR and compound macroscopic analyses provided evidence of the strong interactions that existed between starch and bagasse fibers. The Compound micrographs revealed that the cellulose fibers are well wetted by the starch matrix, and showed that the fibers are strongly attached to the starch matrix since it pulls the matrix out of shape where the fibre is attached during tensile testing.

Results showed that the starch composites reinforced with sugar cane bagasse cellulose fibre have a potential application in biodegradable packaging and biocomposite medical science (Alvarez*et al.*, 2004).Regarding transparency, solubility and density the developed bio plastic at optimal point shows lower transparency, solubility and higher density (13%, 10.7% and 1.068g/ml) compared to control (100% starch) made bioplastic (118%, 14.7% and 1.059g/ml restively) this was due to introduction of fibre intoa starch matrix which from hydrogen bond.

IV.II RECOMMENDATION

- Since this study was done at the micro level to produce bioplastic the future study should focus on Nano scale production and characterization to improve quality, mechanical and physic-chemical properties of fibre reinforced based bioplastic.
- In the future the production of bioplastic reinforced with cellulose extracted from sugarcane bagasse fibre should be modified by controlling mixing temperature and using different technologies such as extrusion, injection molding, blow molding etc.
- In order to explore more effective bioplastic based on starch and cellulose fibre more wide studies should be carried out by considering other processing factors such as drying time, plasticizer, starch gelatinization temperature, fibre particle size and solvents on the quality, mechanical and physicochemical property should be investigated.
- Based on the present study developed bioplastic can be used for food packaging so in the future study focus on the feasibility of using bioplastic for food packaging.

- Since corn starch is edible food it creates problem of food security of our country as well as the world, focus should be given to non-edible based starch source.

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Vighneswara Rao.K, et. al. "Production, Characterization and Optimization of Biodegradable Plastic from Corn starch and Sugarcane Bagasse." *International Journal of Engineering Research and Development*, vol. 17(04), 2021, pp 39-50.