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Research Article

Development of Potato Starch Based Biodegradable Packaging Film

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ABSTRACT

The experiment was conducted at department of processing and food engineering, College of Agricultural Engineering and Technology Junagadh agricultural university during 2019-2020. Development of starch film was carried out at different levels of starch concentration (5, 6.5, 8, 9.5 and 1) and glycerol concentration (0.5, 0.875, 1.250, 1.625 and 2) whereas distilled water 100 ml and acetic acid 1 ml were kept constant throughout the experiment. The films were prepared by casting technique using a film-forming solution. The results on biodegradable film were analysed using Central Composite Rotatable Design (CCRD), Response Surface Methodology with two factors. The physical properties of potato starch powder viz., water absorption index and water solubility index was found as 139% ± 1.53% and 82% ± 1.52%. Physico-chemical properties of potato starch biodegradable plastic viz., moisture content, transparency, water absorption capacity and water vapour permeability was found as 23.1%, 69.54%, 190% and 0.0058 g mm/m2 kPa respectively. The response surface quadratic model for potato starch film optimized the treatment condition as 7.1 g starch concentration and 0.5 ml glycerol concentration.

Keywords: Biodegradable packaging; Potato starch; Glycerol; Biodegradable polymer; Synthetic polymer

INTRODUCTION

Synthetic polymers are important in many branches of industry, particularly in the packaging industry. However, it has an undesirable influence on the environment and causes problems with deposition of waste and consumption. Materials used for food packaging today consists of a variety of petroleum-derived plastic polymer, metals, glass, paper and board. Among these packaging materials, plastic is found to be the best because of its long life properties. Thus, its utilization is increasing every day by day. However, plastics cannot be degraded by natural processes in a short period of time; therefore, they are left as plastic waste, causing environmental problems. Methods normally used to destroy other types of waste such as burning and burying are not suitable for plastic destruction. In response to these problems associated with plastic waste, there has been considerable interest in the development and production of biodegradable plastics [1].

Plastics from natural polymers are biodegradable plastics. Biodegradable plastics will be decomposed due to bacteria, fungi or other micro-organisms that use them as food. New biodegradable biopolymers are developed using biotechnological processes. These biopolymers are termed as "green plastic", which are derived from plants. This green plastic is the topic of the interest for contemporary scientists as it is ancillary of traditional chemical based plastics. The green plastic should be derived from renewable sources; it should be biodegradable in nature and eco-friendly [2].

Starch is a biodegradable polysaccharide, produced in plenty at low expenditure and exhibits thermoplastic in nature. Starch a renewable source, appears to be the best raw material of biodegradable polymer with low cost. Starch from different sources has been studied as a potential film-forming agent, including that from potato and barley, wheat, tapioca, and rice. Thus, it has become most promise alternative material to replace conventional plastics in individual market segments. In this experiment, a biodegradable plastic film was produced by blending potato starch and a glycerol. Films developed from starch are described as isotropic, odorless, colorless, non-toxic and biologically degradable [3].

Potato (*Solanum tuberosum L.*) is one of the world's major agricultural crops and is member of the Solanaceae family. It has been in cultivation since its introduction in the early part of the 17th century and is considered of significant importance as food crop. India is the second largest producer of potato with a production of about 34.4 million MT after China which produces 69.06 million MT. India contributes about 11.26% of the total potato production in the world. Potato starch based biodegradable packaging film is prepared by the method of casting.

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The performance evaluation of film was done by pigeon pea. Finally, the typical petroleum based plastics takes a long time to degrade because of the molecular bonds that make the plastics so durable and equally resistant to natural processes of biodegradation. The main objectives of this research were to produce biodegradable plastic films which are obtained from Potato starch and to study its suitability for the food packaging. These plastic films are to be tested to ensure that these are appropriate for the food packaging.

MATERIAL AND METHODS

Raw materials

Potato starch, glycerol, acetic acid and all other chemicals in analytical grade were procured. Potaro starch was used for preparation of biodegradable plastic film from starch. Glycerol was used as a plasticizer in the filmogenic solution to increase the flexibility and plasticity of the film. Acetic Acid was also added to the solution. In packaging films, acetic acid is added to increase the antimicrobial, plasticizing and dispersing effect in biodegradable/ edible films and to improve the mechanical properties and water vapor permeability. Distilled water was added to solution as it acts as the plasticizer and it decreases the brittleness of plastic films. So water is used to make the solution of starch.

Preparation of film

The films were prepared by casting technique using a film-forming solution containing potato, corn and rice starch individual. Glycerol was used as plasticizer. Starch Concentration (5%, 6.5%, 8%, 9.5% and 11% (W/V)) and Glycerol Concentration (0.5%, 0.875%, 1.25% 1.625% and 2% (V/V)) was taken as variable parameter. Distilled water was added to it. The mixture of dry starch, water and glycerol was taken in a beaker. Then 1 ml of acetic acid was added to the solution. The mixture was mixed with the help of glass rod on heating with stirring on magnetic stirrer at 40°C for 5 minutes. Now the mixture was kept in water bath at 85°C temperature for 15 minutes and continuous agitated by glass road. Now a cast was prepared and the entire solution was poured on the cast and was left for drying at room temp for 24 hrs. After drying the films were peeled off and were kept in poly bags away from moisture (Figure 1).

Thickness of the film

Thickness of the Film was measured with the help of digital Vernier Calipers (Mitutoyo corporation, Japan made, model- CD-12 having a least count of 0.01mm.

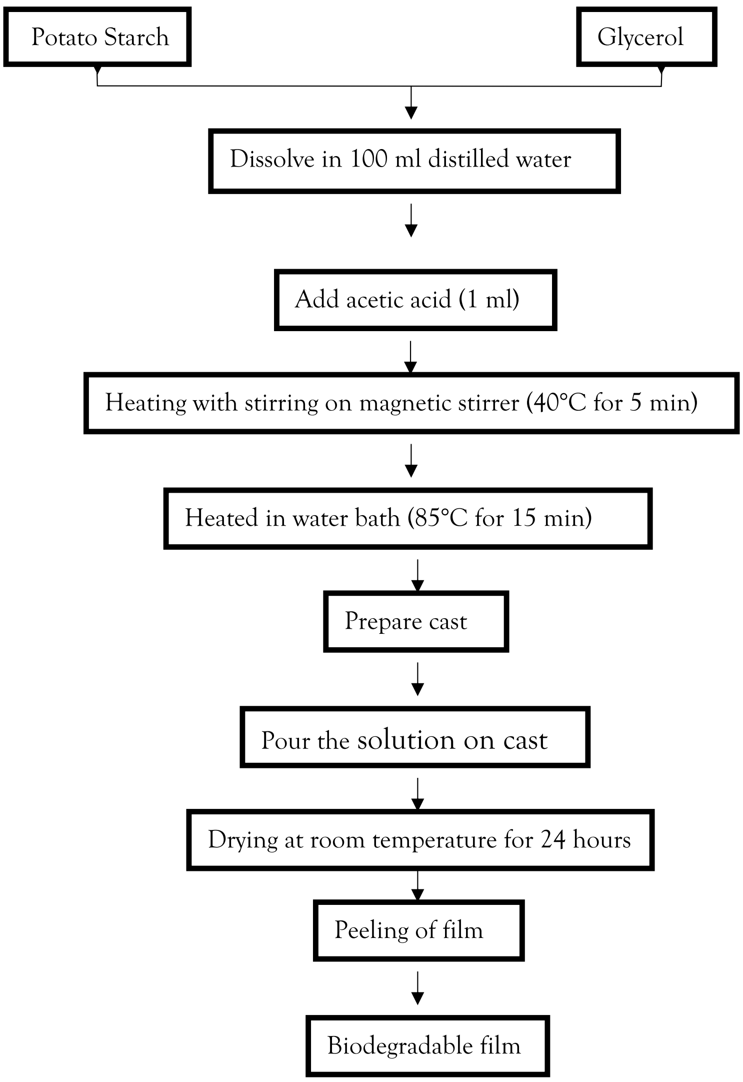

Figure 1: Process flow chart for formation of starch based biodegradable film.

Physico-chemical properties of developed biodegradable packaging film

The physico-chemical properties viz., moisture content, transparency, water absorption capacity, water vapour permeability and surface morphology of developed biodegradable packaging film were determined and surface morphology investigations were performed on thermoplastic starch films of potato starch by using SEM machine model (HITACHI S-3400N) respectively (Table 1).

Experimental design

The experiment was conducted by Response Surface Methodology (RSM) is an empirical statistical modelling technique employed for multiple regression analysis using quantitative data obtained from properly designed experiments. The Central Composite Rotatable Design (CCRD) was used for designing the experiments using Design Expert 10 Software.

RESULTS AND DISCUSSION

Thickness of the film

Thickness of all the samples were measured and the mean thickness were calculated with the use of Vernier Calipers and showed that the mean thickness were in the range of 0.11 mm to 0.16mm. The result was agreement with reported that increasing the starch in the formulation, the films were thicker (Table 2) [4].

Physico-chemical properties of potato starch biodegradable packaging film

The different physico-chemical properties of potato starch biodegradable plastic were analysed and studied viz., moisture content, transparency, water absorption capacity, water vapour permeability and surface morphology were carried out as per methods and results were tabulated in Table 3.

Table 1: Treatments combinations.

Run	Starch Concentration, % (W/V)	Glycerol Concentration % (V/V)
1	8.0	1.250
2	8.0	1.250
3	8.0	1.250
4	9.5	1.625
5	5.0	1.250
6	6.5	0.875
7	9.5	0.875
8	8.0	1.250
9	11.0	1.250
10	8.0	1.250
11	8.0	1.250
12	8.0	2.000
13	6.5	1.625
14	8.0	0.500

Table 2: Thickness of potato starch film.

Run	Thickness (mm)
1	0.14
2	0.15
3	0.12
4	0.14
5	0.11
6	0.16
7	0.16
8	0.12
9	0.14
10	0.15
11	0.14
12	0.12
13	0.15
14	0.15
Mean	**0.14**

Table 3: Different physico-chemical properties of potato starch biodegradable packaging film.

Std. run	Starch concentration, %	Glycerol concentration %	Moisture content %	Transparency %	Water absorption capacity %	Water vapour permeability g mm/m2 day Kpa	Tensile strength, MPa	Puncture strength, MPa
1	6.5	0.88	19.22	67.31	156	0.004	7.01	6.35
2	9.5	0.88	21.4	59.63	178	0.005	11.76	8.97
3	6.5	1.63	19.72	66.25	161	0.004	6.23	5.31
4	9.5	1.63	22.32	58.23	183	0.005	11.07	8.36
5	55	1.25	18.19	69.54	151	0.004	5.09	4.28
6	11	1.25	23.1	52.86	190	0.006	13.62	10.5
7	8	0.5	18.73	63.21	165	0.004	10.58	7.83
8	8	2	21.22	60.9	176	0.005	8.54	6.95
9	8	1.25	20.23	64.23	173	0.005	10.36	7.47
10	8	1.25	20.43	62.31	167	0.004	10.47	7.36
11	8	1.25	20.46	62.45	172	0.005	9.85	7.28
12	8	1.25	19.93	62.85	171	0.005	10.2	7.08
13	8	1.25	19.95	63.1	168	0.004	9.5	7.39
14	8	1.25	19.96	64.76	169	0.005	9.78	7.53

Effect of starch and glycerol concentration on moisture content of potato starch based biodegradable film

Moisture content of potato starch film was ranged from 18.19% to 23.1%. The maximum moisture content was observed for the combination 11 g of starch concentration and 1.25 ml glycerol concentration and minimum moisture content was found for the combination of 5 g starch concentration and 1.25 ml glycerol concentration. The effect of starch and glycerol concentration on moisture content of potato starch biodegradable film is presented in Table 3.

The response surface curve of variation in the moisture content of potato starch biodegradable plastic as a function of starch concentration ("X"_"1") and glycerol concentration ("X"_"2") is shown in (Figure 2). The contour plot for moisture content of potato starch biodegradable plastic film as a function of starch concentration ("X"_"1") and glycerol concentration ("X"_"2") is presented in the (Figure 3) which indicated the increase in moisture content as the starch concentration was increased up to maximum level and increase in glycerol concentration up to maximum level. At this combination, moisture content of potato starch biodegradable plastic film was predicted 24.55 %. The result was agreement with the results. Similar results were reported in (2020) in purple sweet potato starch film in corn starch film [5-7].

The regression analysis and ANOVA results for the moisture content of potato starch plastic are shown in the Table 4. It can be seen from the table, that starch and glycerol concentration showed positive linear effect which significant at p<0.001. Whilst, the interaction effect of starch concentration and glycerol concentration was positively non-significant and the quadratic effect of starch concentration was positively non- significant and

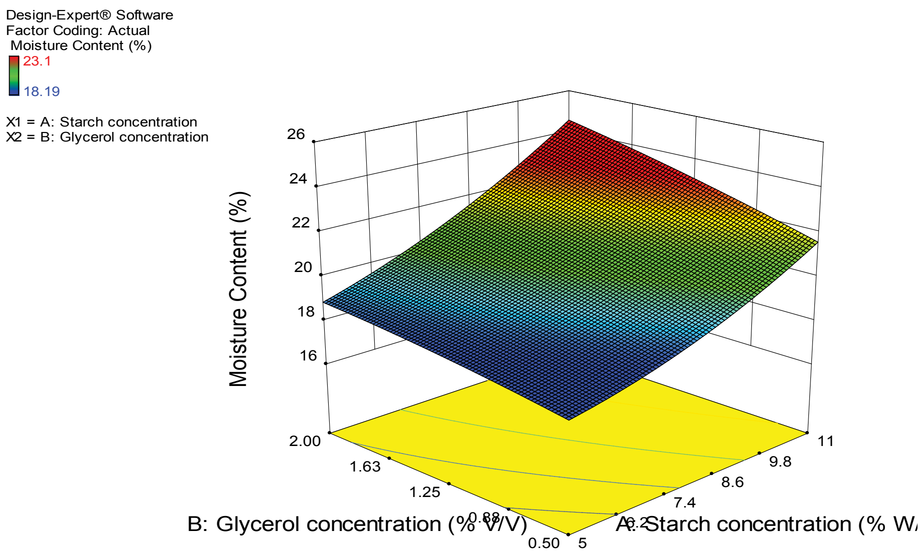

Figure 2: Response surface plot for moisture content of potato starch biodegradable film.

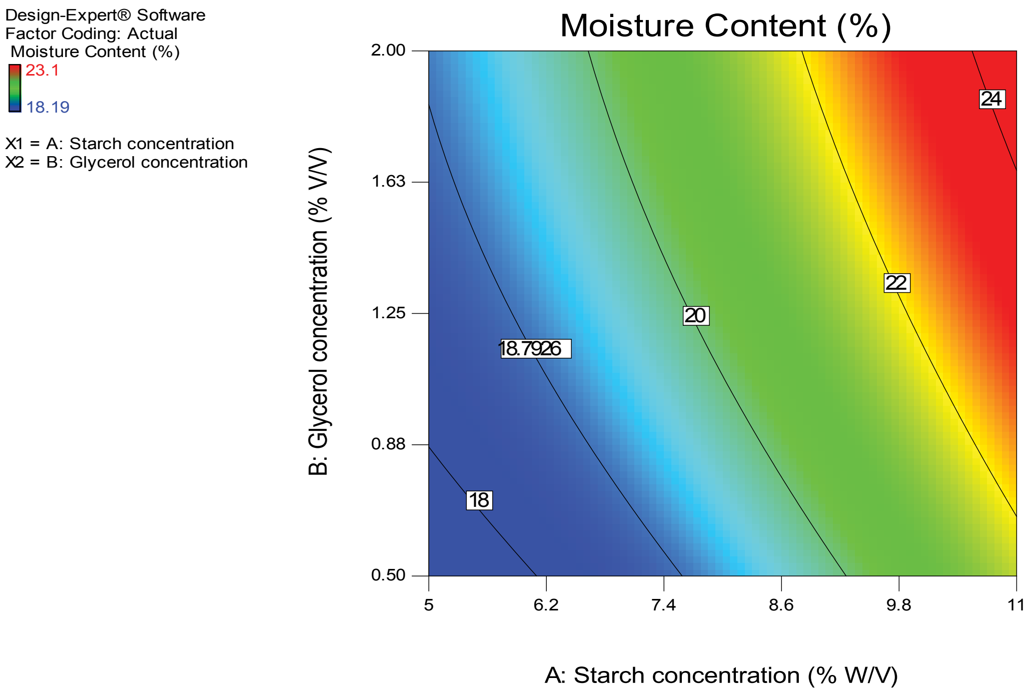

Figure 3: Contour plots for moisture content of potato starch biodegradable film.

quadratic effect of glycerol concentration was negatively non-significant on moisture content (Table 3 and Table 4).

Effect of starch and glycerol concentration on transparency of potato starch based biodegradable film

Transparency of potato starch film was ranged from 52.86% to 69.54%. The maximum transparency was observed for the combination of 5 g starch concentration and 1.10 glycerol concentration and minimum transparency was found for the combination of 11g starch concentration and 1.25 ml glycerol concentration. The effect of starch and glycerol concentration on transparency of potato starch biodegradable film is presented in Table 3.

The response surface curve of variation in the transparency of potato starch biodegradable plastic film as a function of starch concentration ("X"_"1") and glycerol concentration ("X"_"2") is shown in (Figure 4). It represents the interactive effect of starch concentration and glycerol concentration on the, transparency of potato starch film. The contour plot for transparency of potato starch biodegradable plastic film as a function starch concentration ("X"_"1") and glycerol concentration ("X"_"2") is presented in (Figure 5) which indicated the increase in transparency as the starch concentration was decreased up to minimum level and transparency was increased with an increase in glycerol concentration up to 1.10 ml then further increase in glycerol concentration transparency was decreased. Transparency at the combination of 5 g starch

Table 4: Analysis of Variance (ANOVA) table and regression coefficients for response surface quadratic model of different physico-chemical properties of potato starch biodegradable packaging film.

Source	Moisture content	Transparency	Water absorption capacity	Water vapor permeability	Tensile strength	Puncture strength
Intercept	+20.16	+63.38	+169.09	+4.543E-003	+9.86	+7.32
Linear terms						
$A(X_1)$	$+1.22^{***}$	-4.09^{***}	$+10.17^{***}$	$5.425E004^{***}$	$+2.22^{***}$	$+1.50^{***}$
$B(X_2)$	$+0.53^{***}$	-0.59*	$+2.67^{**}$	+7.583E-005	-0.46^{*}	-0.28^{***}
Interaction terms						
$AB(X_1 X_2)$	+0.10	-0.085	+2.82878E-014	-1.750E-005	+0.023	+0.11
Quadratic terms						
$A^2(X_1^2)$	+0.13	-0.51^{**}	+0.10	$+5.724E\text{-}005^{*}$	-0.19	-1.103E-004
$B^2(X_2^2)$	-0.034	-0.30	+0.10	+3.493E-006	-0.14	+6.140E-003
Indicators for model fitting						
R^2	0.9552	0.9744	0.9751	0.968	0.9628	0.9892
Adj-R^2	0.9272	0.9585	0.9595	0.9489	0.9395	0.9825
Pred-R^2	0.7391	0.9470	0.9316	0.9054	0.7923	0.9346
Adeq Precision	20.81	29.97	30.16	27.11	24.61	46.92
F-value	34.13	61.01	62.55	49.29	41.36	146.90
Lack of fit	NS	NS	NS	NS	NS	NS
C.V%	1.76	1.33	1.21	2.66	5.76	2.67

A or X1=Starch Concentration, B or X2=Glycerol Concentration, ***Significant at p<0.001, **Significant atp<0.01, *Significant at p<0.05, NS=Non-Significant

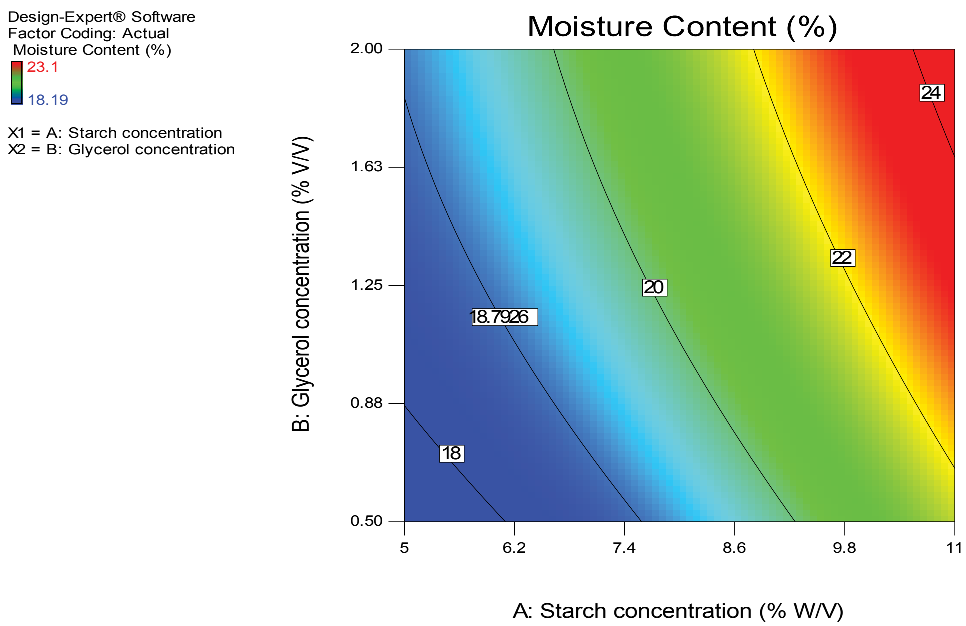

Figure 4: Response surface plots for transparency of potato starch biodegradable film.

concentration and 1.02 ml glycerol concentration may be observed 69.65%. The result was agreement with the result. Similar result (2018) in film made from alginate [8,9].

The regression analysis and ANOVA results for the transparency of potato starch film are shown in the (Table 5). It can be seen from the table, that starch concentration showed negative linear effect on transparency which there were significant at $p<0.001$ also glycerol concentration showed negative linear effect on transparency which was significant at $p<0.05$. Whilst, the interaction effect of starch concentration and glycerol concentration was negatively non-significant and the quadratic effect of starch concentration showed negatively significant at $p<0.01$ and glycerol concentration was negatively non-significant on transparency.

Effect of starch and glycerol concentration on water absorption capacity of potato starch based biodegradable film

Water absorption capacity of potato starch film was ranged from 151% to 190%. The maximum water absorption capacity was observed for the combination of 11 g starch concentration and 1.25 ml glycerol concentration and minimum water absorption capacity content was found for the combination of 5 g starch concentration and 1.25 ml glycerol concentration. The effect of starch and glycerol concentration on water absorption capacity of potato starch biodegradable film is presented in Table 3.

The response surface curve of variation in the water absorption capacity of potato starch biodegradable plastic film as a function of starch concentration ("X"_"1") and glycerol concentration ("X"_"2") is shown in (Figure 6). It represents the interactive effect of starch concentration and glycerol concentration on the, water absorption capacity of potato starch film. The contour plot for water absorption capacity of potato starch biodegradable plastic film as a function of starch concentration ("X"_"1") and glycerol concentration ("X"_"2") is presented in the (Figure 7) which indicated the increase in water absorption capacity as the starch and glycerol concentration was increased up to maximum level. At this combination, the water absorption capacity of potato starch film was predicted up to 145 %. The result was agreement with result reported in wheat starch film and similar result was found by (2008a) in rice starch-chitosan film [10,12].

The regression analysis and ANOVA results for the water absorption capacity of potato starch film are shown in the Table 4. It can be seen from the table, that starch concentration showed positive linear effect on water absorption capacity which there were significant at $p<0.001$ also glycerol concentration showed positive linear effect on water absorption capacity which was significant at $p<0.01$. Whilst, the interaction effect of starch concentration and glycerol concentration was positively non-significant and the quadratic effect of starch concentration and glycerol concentration was positively non-significant on water absorption capacity.

Effect of starch and glycerol concentration on water vapor permeability of potato starch based biodegradable film

Water vapor permeability of potato starch film was ranged from 0.00371 g mm to 0.00580 g mm/m2kPa The maximum water vapor permeability was observed for the combination of 11 g starch concentration and 1.25 ml glycerol concentration and minimum water vapor permeability was found for the combination of 5 g starch concentration and 1.25 ml glycerol concentration. The effect of starch and glycerol concentration on water vapour permeability of potato starch biodegradable film is presented in Table 3.

The response surface curve of variation in the water vapor permeability of potato starch biodegradable plastic film as a function of starch concentration ("X"_"1") and glycerol concentration ("X"_"2") is shown in (Figure 8). It represents the interactive effect of starch concentration and glycerol concentration on the, water vapor permeability of potato starch film. The contour plot for water vapor permeability of potato starch biodegradable plastic film as a function of starch concentration ("X"_"1") and glycerol concentration ("X"_"2") is presented in the (Figure 9) which indicated the decrease the starch and glycerol concentration,

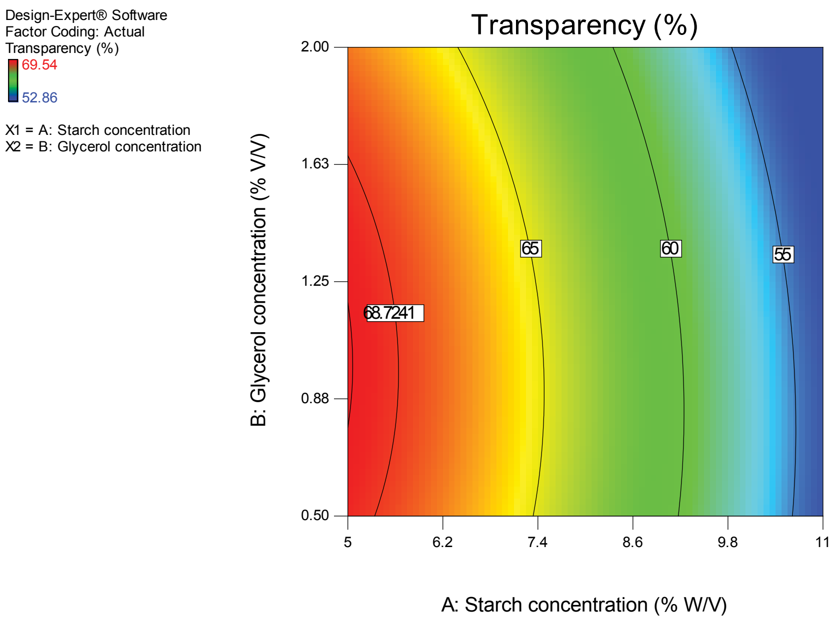

Figure 5: Contour plots for transparency of potato starch biodegradable film.

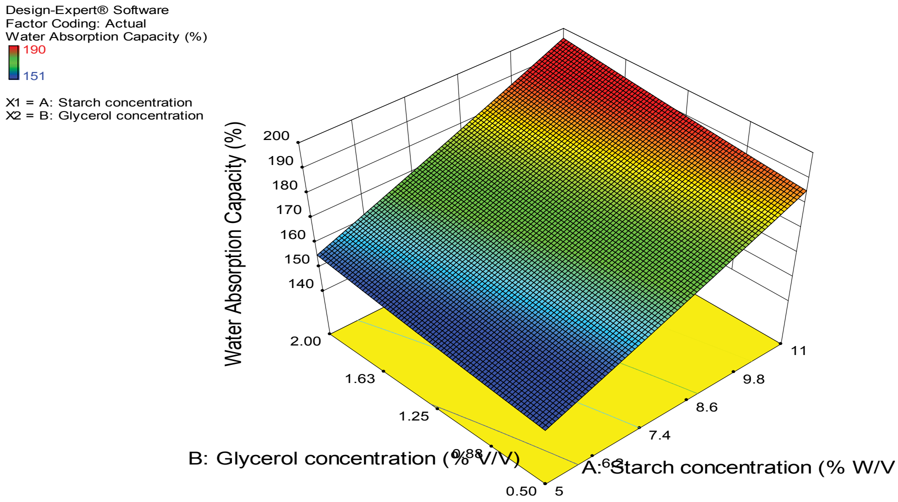

Figure 6: Response surface plots for water absorption capacity of potato starch biodegradable film.

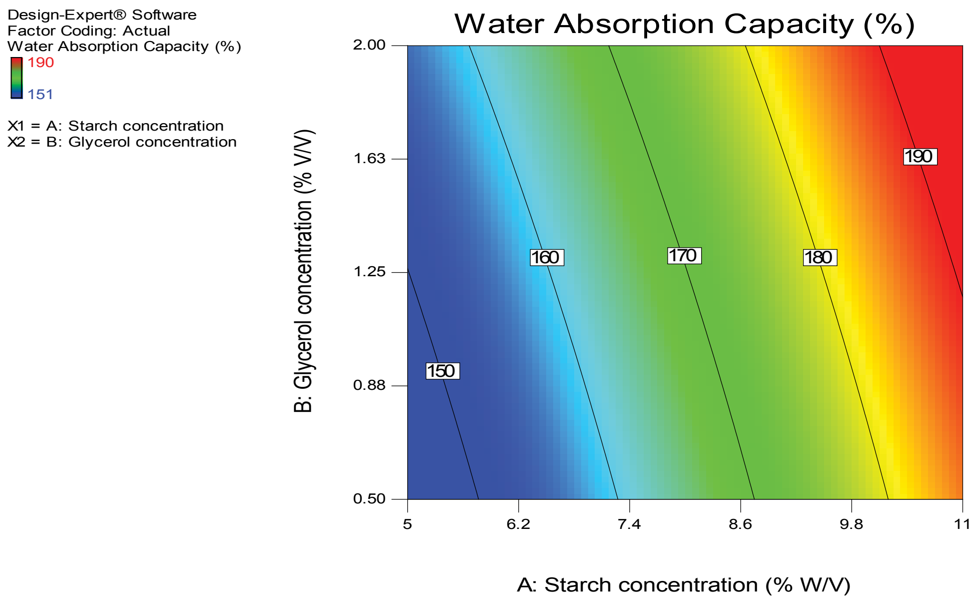

Figure 7: Contour plots for water absorption capacity of potato starch biodegradable film.

water vapour permeability was decreased up to minimum level. At this combination, the water vapour permeability of potato starch film was predicted up to 0.00348 g.mm/m2 kPa. The result was agreement with the result reported (2013) in corn starch films incorporated with plant essential oils. Similar result was found (2013) in films made of wheat starch and glycerol (2015) in sugar palm starch film incorporated with glycerol and sorbitol [10,11].

The regression analysis and ANOVA results for the water vapor permeability of potato starch film are shown in the Table 4. It can be seen from the table, that starch concentration showed positive linear effect on water vapor permeability which there were significant at $p<0.001$ also glycerol concentration showed positive linear effect on water vapor permeability which was non-significant. Whilst, the interaction effect of starch concentration and glycerol concentration was negatively non-significant and the quadratic effect of starch concentration was positively significant at $p<0.05$ and glycerol concentration was positively non-significant on water vapor permeability [13].

Surface morphology of developed potato starch packaging film.

The surface morphology of potato starch/glycerol films was studied with SEM was seen in (Figure 10) In order to have the conducting impact, the samples were gold plated and the scanning was synchronized with microscopic beam so as to maintain the small size over a large distance relative to the specimen. The resulting images had a great depth of the field. A remarkable three dimensional appearance with high resolution was obtained in case of cross linked matrix.

The potato starch films had several unequaled holes, suggesting that the miscibility and compatibility in each component in potato starch films were increased. With increase in glycerol content the surface of the film gets smoother.

From the SEM micrograph, it can be concluded that the potato starch granules dispersed well in the glycerol. This dispersion helps to improve the mechanical properties of the film and shows an agreement with the tensile property results.

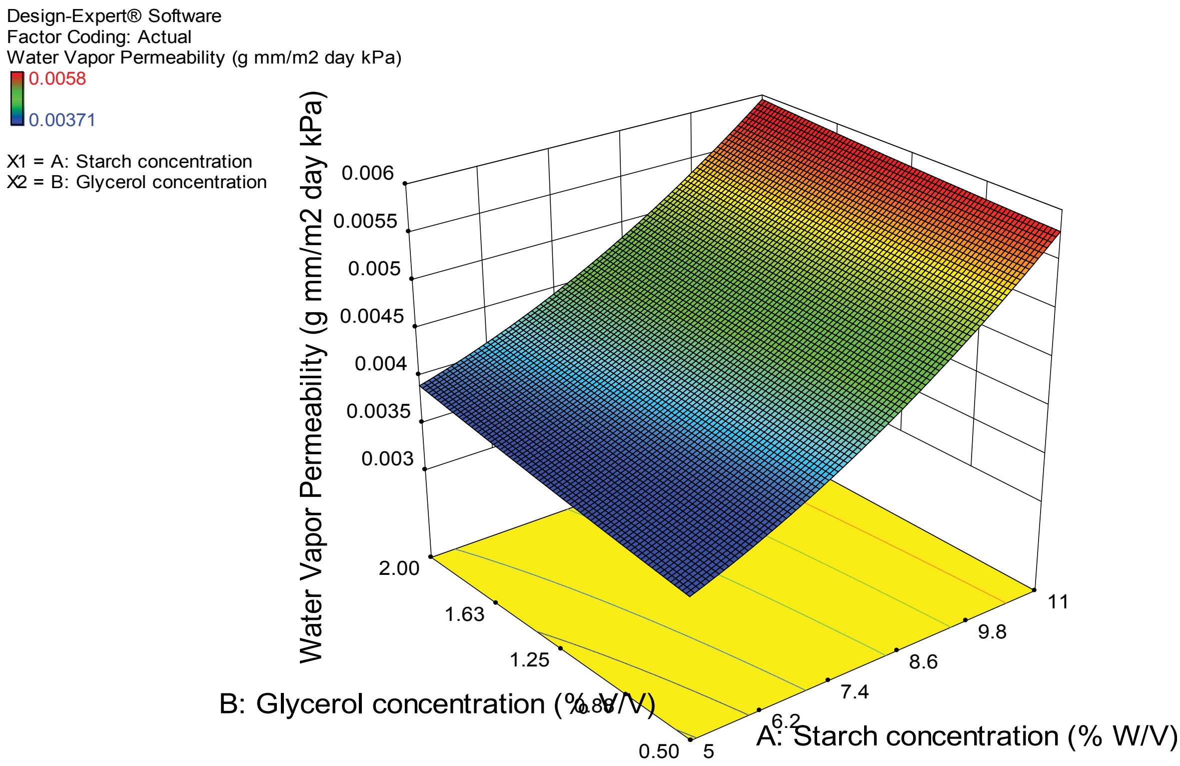

Figure 8: Response surface plots for water vapor permeability of potato starch biodegradable film.

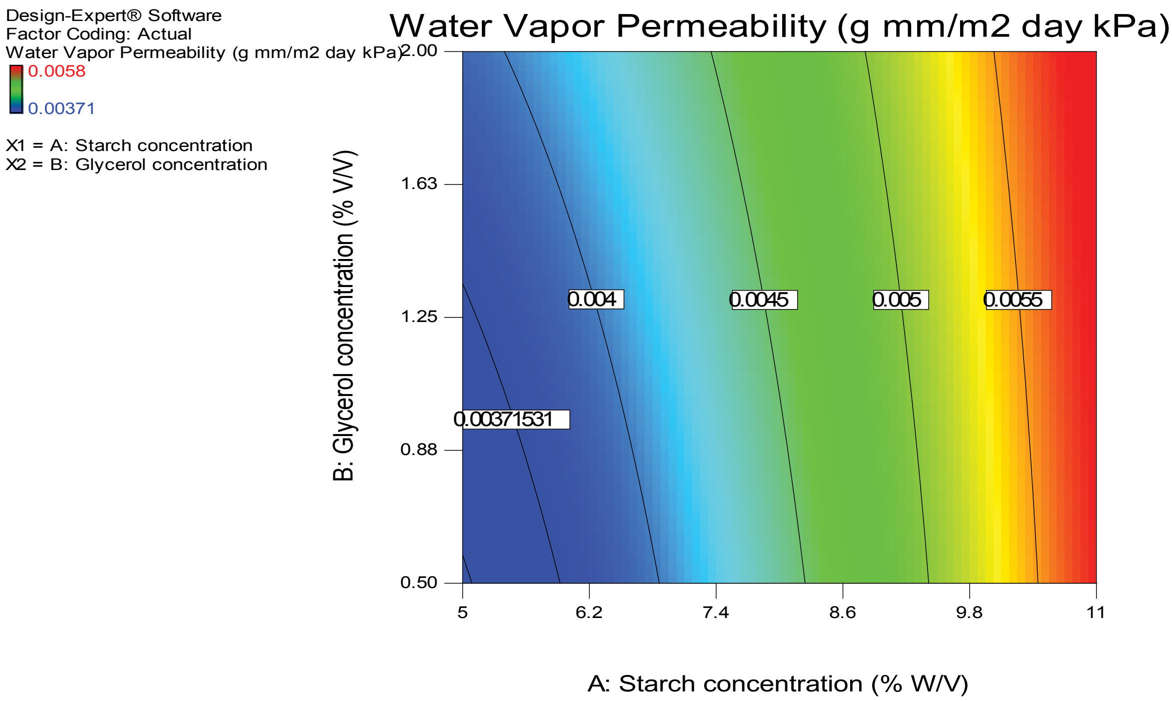

Figure 9: Contour plots for water vapor permeability of potato starch biodegradable film.

Optimization and validation of process variables

The optimum condition for the development of starch based biodegradable film was determined by the numerical optimization technique, using Design Expert software version 10 (State-Ease Inc., Minneapolis, MN, USA). The optimum treatment conditions for potato starch film were found to be, 7.1 g starch concentration and 0.5 ml glycerol concentration. The analysis showed that at this combination of starch and glycerol concentration, it would be possible to produce a potato starch based biodegradable plastic film with a moisture content of 18.52%, transparency 65.47%, water absorption capacity 159%, water vapour permeability 0.004 g mm/m2 day KPa.

Performance evaluation of potato starch biodegradable film for packaging

Packaging is any product that is used to hold, protection, handling,

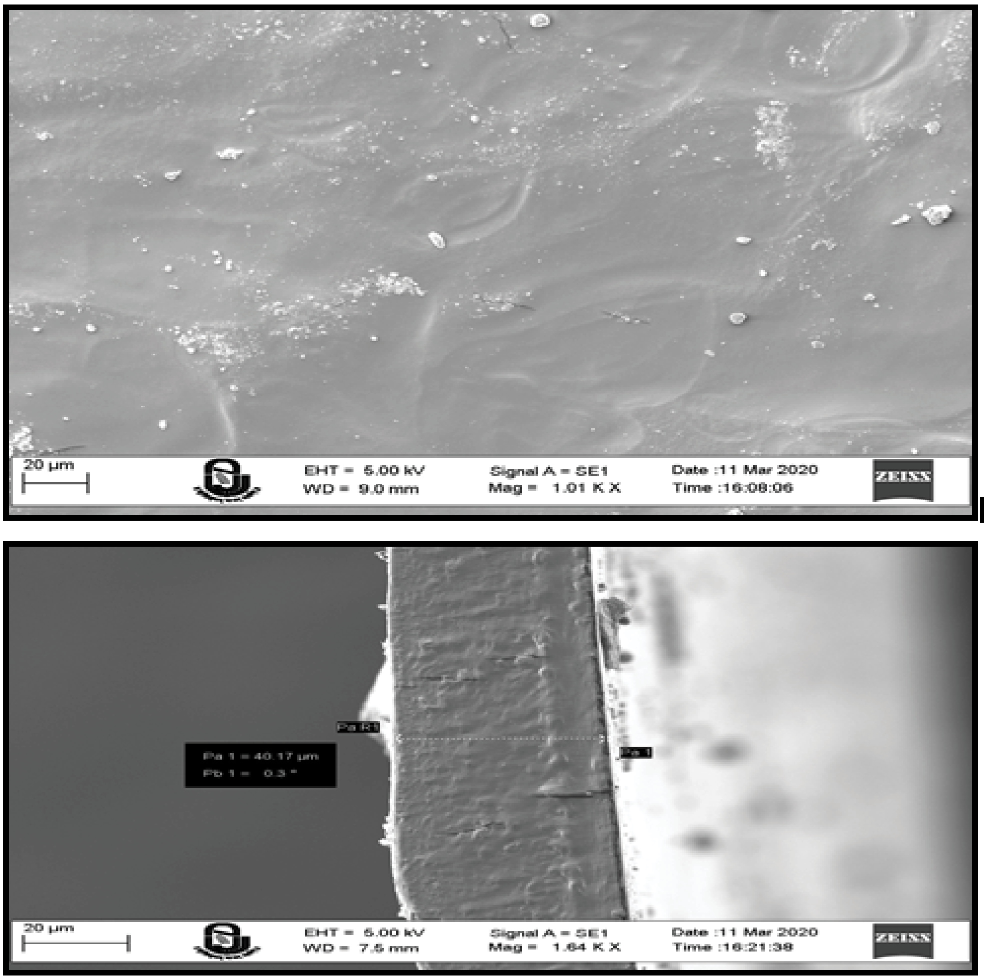

Figure 10: Scanning electron microscopic images of cross-section of potato starch film; (A): Surface or top view; (B): Side view.

Figure 11: Pigeon pea packed in potato starch film starch film.

delivery and presentation of goods, from raw materials to finished products, from producers to consumers. The ability of developed biodegradable film to seal at sides and corners to form plastic carry bag was evaluated. The results indicated that the prepared bioplastic samples have good sealing capabilities. The heat-sealing feature was estimated through visual inspection. The sample was inspected manually. The sealed sample seems have excellent sealing properties. Since sealing properties are important for preparing plastic bags, hence, it is concluded that the bioplastics produced in this project can used to manufacture bioplastic carry bags. A sample bag produced from the starch is used for packaging is shown in Figure 11.

CONCLUSION

Biodegradable plastics have been successfully produced from potatoes using the aforementioned approach and experimental procedures. The plastic samples produced were characterized in order to determine their physical and physico-chemical properties. Based on the results obtained, it could be concluded that the feedstock, potatoes, which are available in large quantity or it is a good source of starch for the production of biodegradable plastics. Their renewability and minimization of environmental pollution/ hazards are great achievement [14-16]. The moisture content of the film was increase with increase the starch and glycerol content. This behavior could be explained because increasing the starch content promotes the formation of more hydrogen bridges and plastic containing glycerol absorb more moisture which is likely due to the hydrophilic nature of glycerol. Transparency of the film was decreases with increase the starch concentration and glycerol concentration due to more molecules of starch give lighter color of film. Water absorption capacity of the film increasing with the starch and glycerol content due to starch and glycerol hydrophilic in nature. Water vapor permeability increase with increase the glycerol content due to hydrophilic nature of biopolymers and presence of voids in their structure have a considerable influence on the WVP of resulting films. This data can be used to design specific food packaging film system.

REFERENCES

1. Salgado PR, Schmidt VC, Ortiz SE, Mauri AN, Laurindo JB. Biodegradable foams based on cassava starch, sunflower proteins and cellulose fibers obtained by a baking process. J Food Eng. 2008;85:435-443.
2. Tharanathan RN, Srinivasa PC, Ramesh MN. A process for production of biodegradable films from polysaccharides. Indian patent. 2002;85.
3. Flores S, Famá L, Rojas AM, Goyanes S, Gerschenson L. Physical properties of tapioca-starch edible films: Influence of filmmaking and potassium sorbate. Food Res Int. 2007;40:257-265.
4. Thakur R, Saberi B, Pristijono P, Stathopoulos CE, Golding JB, Scarlett CJ, et al. Use of Response Surface Methodology (RSM) to optimize pea starch-chitosan novel edible film formulation. J Food Sci Technol. 2017;54:2270-2278.
5. Talja RA, Helén H, Roos YH, Jouppila K. Effect of type and content of binary polyol mixtures on physical and mechanical properties of starch-based edible films. Carbohydr Polym. 2008;71:269-276.
6. Buso Rios OI, Velázquez G, Járquin E L, Flores M NL. Effect of the concentration of starch and clove essential oil on the physicochemical properties of biodegradable films. Rev Mex Ing Quim. 2020;19:1315-1326.
7. Kibar EA, Us F. Thermal, mechanical and water adsorption properties of corn starch-carboxy methyl cellulose/methyl cellulose biodegradable films. J Food Eng.2013;114:123-131.
8. Dai H, Chang PR, Geng F, Yu J, Ma X. Preparation and properties of starch-based film using N, N-bis (2-hydroxyethyl) formamide as a new plasticizer. Carbohydr Polym. 2010;79:306-311.
9. Khairunnisa S, Junianto J, Zahidah Z, Rostini I. The effect of glycerol concentration as a plasticizer on edible films made from alginate towards its physical characteristic. World Sci News. 2018;112:130-141.
10. Farahnaky A, Saberi B, Majzoobi M. Effect of glycerol on physical and mechanical properties of wheat starch edible films. J Texture Stud. 2013;44:176-186.
11. Bourtoom T. Plasticizer effect on the properties of biodegradable blend film from rice starch-chitosan. Warasan Songkhla Nakharin. 2008;30.
12. Ghasemlou M, Aliheidari N, Fahmi R, Shojaee Aliabadi S, Keshavarz B, Cran MJ, et al. Physical, mechanical and barrier properties of corn starch films incorporated with plant essential oils. Carbohydr Polym. 2013;98:1117-11126.
13. Sanyang ML, Sapuan SM, Jawaid M, Ishak MR, Sahari J. Effect of plasticizer type and concentration on tensile, thermal and barrier properties of biodegradable films based on sugar palm (Arenga pinnata) starch. Polymers. 2015;7:1106-1124.
14. AOAC. Official methods of analysis. Association of Analytic Chemist. 2005 https://www.aoac.org/
15. ASTM D570-98. Standard Test Method for Water Absorption of Plastics. ASTM International.1998. www.astm.org
16. ASTM E96-95. Standard Test Methods for Water Vapour Transmission of Materials, Annual Book of ASTM. American Society for Testing and Materials. 1995. www.astm.org.