The Effect of Cornstarch Levels on the Surface Quality of Extruded Soy Protein Plastic

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Abstract

The ratio of soy protein isolate to cornstarch was studied in the extrusion of four different formulations of soy protein plastic in order to qualitatively examine the surface quality upon extrusion. Levels of glycerol and moisture were constant across all samples, and no other additives were used in the mixtures. Mixtures were made using a planetary mixer, and then extruded using a single-screw extruder equipped with a 10.16 centimeter sheeting die with a 0.152-centimeter opening. The surface of the extruded plastic became smoother with increasing starch content, but the processability became too difficult with very high starch levels.

Keywords: soy protein plastic, biopolymers, sheet extrusion

1. Introduction

With increasing awareness of the environmental hazards surrounding petroleum-based plastics, many have started researching alternative materials to avoid these risks. One of the primary environmental issues for any material is its relative biodegradability. While petrochemicals have dominated the plastics industry for the last 70 years, there are concerns about the extended use of conventional plastics and the effect they may have on the environment.[1] A widespread system for plastics recycling is available in most areas of the United States, but the system largely relies on the consumer to take responsibility for his or her own refuse. For these reasons, demand for biodegradable plastics, such as those made using a soy protein base, has risen in recent years.

1.1 Forms of soy protein

The three basic forms of soy protein are soy flour, soy protein concentrate, and soy protein isolate. Soy flour is produced by grinding soybeans into a powder, discarding the hulls, and extracting the oil. Soy protein concentrate, a more purified form that contains approximately 65% protein, is made by leaching out all of the water soluble carbohydrates from soy flour.[2] Soy protein isolate, the purest and most expensive form, can be produced by a chemical treatment process to bring the soy to an approximate 90% protein content.[2] Much of the research done today on soy protein plastics is done using soy protein isolate to better manage the levels of each component in the mixture prior to processing.

1.2 Early research in soy protein plastics

The concept of using soy protein in both plastics and adhesives has existed as early as the 1910s. Patents were first issued in 1913 and 1917 for preparing plastics from a soy protein base.[1] In the early 1930s, Ford Motor Company researched methods to develop and produce a soy-based resin that would be used in their vehicles for interior plastic components. This and prior research was ultimately abandoned because of the industry's overall move towards plastics based on petrochemicals for their wide availability, easy processability, and lower price.[1]

Today, the market is beginning to return its focus toward the possibilities of more widespread use of soy protein plastics.[1] The prospect of global climate change and the volatility of oil supply and price is driving a demand for plastics made from materials other than petrochemicals. Environmentalists have been pushing for research in the area of biopolymers as a way to reduce the amount of plastic consumed in the world.[2] In order to reduce petroleum-based plastic use on the consumer level, further advancements must be made to allow for using biopolymers in consumer plastics.

1.3 Recent research in soy protein plastics

The primary areas of research on soy protein-based plastics are to reduce the cost of soy protein plastic products, and to improve both their short- and long-term mechanical performance.[3] Recent research has already shown that various polyols (such as sorbitol and glycerol) and water will plasticize soy protein effectively, but each of the plasticizing agents created somewhat different properties in the resulting plastics.[4] Some alcohols studied for use as plasticizers are toxic to humans, so the type of plasticizer used depends on the application of the final product.[3] Like different kinds of plastics, different formulations and the soy-to-plasticizer ratio will also affect the applications in which the plastic can be used.

One of the main problems currently hindering the use of soy-based plastic in consumer product applications is the relative processability of these new biopolymers in comparison to the current consumer-grade plastics on the market. The research world knows little about the behavior of soy protein plastics when they are formed or molded using the common methods of processing petrochemical polymers. Recently, however, several research groups have done studies on the molecular composition[5] or mechanical properties of extruded or compression-molded plastic.[6,7]

At the University of Wisconsin–Madison, recent studies have focused on the rheology of soy protein isolate-based plastics,[8] and this project is continuing to expand on that research through the examination of different formulations of soy-based plastics and the surface quality after extrusion. This sheet extrusion research focuses on altering the levels of cornstarch and soy protein in the different formulations, while maintaining the levels of water and glycerol in each composition.

2. Procedure

Four different formulations of soy protein-based plastics were explored by altering the ratios of soy protein isolate and starch. Soy protein isolate was used instead of soy protein concentrate in order to more carefully manage the ratio of protein and starch in the formulations. These formulations were then extruded using a single-screw extruder with a 10.16 centimeter wide sheeting die to extrude an approximate 0.152-centimeter thick profile. The extrudate quality was examined qualitatively, with careful attention to the surface properties and the consistency of the plastic.

2.1 Formulations

Each formulation was composed of soy protein isolate, cornstarch, lab grade glycerol, and deionized water. The formulations, shown in Table 1, are variations of those used by Ralston.[8]

The moisture content of each component of the formulations was tested using a moisture analyzer. The moisture content was factored into the calculation to find the dry weight of the components needed in each formulation.

Formulations by % weight				
	A	B	C	D
Soy Protein Isolate	31.2	26	20.8	13
Starch	20.8	26	31.2	39
Glycerol	18	18	18	18
DI Water + Moisture	30	30	30	30

Table 1. Composition of the formulations by weight percent

2.2 Preparation

To prepare each formulation, the soy protein isolate and cornstarch were measured and blended using a planetary mixer for five minutes before adding the glycerol and deionized water. Each mixture was then blended in the planetary mixer for ten more minutes. The sides of the mixing bowl were scraped, and any large pieces of material were broken apart. Each formulation was then mixed for an additional fifteen minutes.

Each formulation was blended until the consistency was that of a damp powder. Approximately 500g of each formulation was produced, and was extruded immediately following the mixing process to reduce moisture loss.

2.3 Extrusion

Each formulation was extruded using a single-screw Brabender plasticorder extruder, with a 10.16 centimeter wide sheeting die set at 0.152 centimeters in thickness, at variable speed between 15 and 50 RPM. The temperature zones were set at 90°C, 125°C, 135°C, and 105°C from the first zone, immediately following the feed throat, to the die. These temperatures were chosen since it has been shown that an optimal injection molding temperature for soy protein plastics is 130°C.[9] Though the plastic was not being injection molded, the soy was still being processed though an outlet with a small thickness.

3. Results and Discussion

For the purposes of this experiment, all observations were qualitative in nature. Large differences were exhibited in the processability and surface quality between each of the four formulations, so higher precision was unnecessary for the scope of the project.

3.1 Observations during extrusion

Formulations A and B, the formulations with lower cornstarch content, exhibited some tearing at the die during extrusion. Formulation A showed high tearing on the edges and some roughness on the top and bottom faces of the extrudate, where formulation B exhibited very little tearing on the edges and smoother top and bottom faces.

Formulation C extruded with a fairly smooth overall surface, and exhibited virtually no tearing at the edges of the plastic. This mixture seemed to extrude the most easily of all tested formulations.

Finally, formulation D extruded with some difficulty and was unable to completely fill the die with material. The powder would frequently squeeze back out toward the feed throat, even when the screw was not filled with material. Nevertheless, the surface quality of this formulation was smooth and comparable to formulation C.

3.2 Observations after extrusion

All four formulations behaved similarly while cooling. The extrudate was still flat and flexible, even when it was cool to the touch. After it sat in open air overnight, the plastic was much harder and curled slightly from the center to the edges across the width of the extrudate. All of the formulations could be either cut with scissors or scored with a blade after this overnight drying period.

Formulations A through C all retained a similar surface quality, but formulation D had a drier appearance after drying overnight.

3.3 Analysis of observations

Formulation A exhibited tearing at both the edges and the top and bottom surfaces of the extrudate, and formulation B showed only some mild tearing on the surfaces. It is assumed that since the only difference between the two mixtures is the increased level of starch in formulation B, that the higher starch content was the reason for the improved surface quality. The extrusion of formulation C further supported this statement, because little to no tearing was observed on either surface or the edges of the extruded material.

The difficulty with formulation D indicates that an upper limit does exist in processing this basic formulation of soy protein plastic effectively. The results for formulation D were also poor when compared to formulation C. The addition of other additives, such as soy oil, may be useful to the processing of the plastic and further refine the extrudability of these basic formulations.

3.4 Mold growth

Prior to extrusion, formulations that were mixed and then stored in plastic bags began to grow mold after one and a half weeks of storage. The cause of this mold growth is unknown, as previous formulations of soy protein plastic did not exhibit this problem. After extruding, mold growth does not appear to be an issue.

4. Conclusions

4.1 Feasibility

Increasing levels of cornstarch in the soy protein plastic formulations clearly have an effect on the surface quality of the final extruded plastic film. While the exact cause for these differences remains unknown, it is possible that the inclusion of cornstarch reduces the coefficient of friction between the plastic and the metal screw and die. This idea could also explain why formulation D had such difficulty in processing; very low friction could cause the plastic to slip on the screw too easily, which will reduce the overall processability.

Formulation C exhibited the most feasible combination of processability and final surface condition out of the four mixtures tested. Since the ratio of starch to soy protein isolate was 3:2, it is possible that soy protein concentrate and cornstarch could be used in the mixtures to produce similar results. The lower cost of soy protein concentrate could allow more inexpensive but comparable materials to be produced.

4.2 Future research

This research could be continued by looking for a more optimal starch level, and also by comparing the results of this research to qualitative properties of the extrudate after including other additives in the mixture, such as soy oil. Also, testing the tensile properties, water resistance, variance of the coefficient of friction, and biodegradability of the extruded material can continue the optimization process. These properties can be compared to those of conventional petrochemical plastics. Finally, comparative mixtures could be tested using soy protein concentrate in place of soy protein isolate to see the variability in properties between the two grades of soy protein.

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References

[1] Myers, D.J. Industrial applications for soy protein and potential for increased utilization. *Cereal Foods World* **1993**, *38*, 355-360.

[2] Swain, S. N., Biswal, S. M., Nanda, P. K., Nayak, P. L. Biodegradable soy-based plastics: opportunities and challenges. *J. Polym. Environ.* **2004**, *12*, 35-42.

[3] Kumar, R., Choudhary, V., Mishra, S., Varma, I.K., Mattiason, B. Adhesives and plastics based on soy protein products. *Ind. Crops Prod.* **2002**, *16*, 155-172.

[4] Wang, S., Zhang, S., Jane, J.L., Sue, H.J. Effect of polyols on mechanical properties of soy protein. *Polym. Mater. Sci. Eng.* **1995**, *72*, 88-89.

[5] Choi, S. G., Kim, K. M., Hanna, M. A., Weller, C. L., Kerr, W. L. Molecular dynamics of soy-protein isolate films plasticized by water and glycerol. *J. Food Sci.* **2003**, *68*, 2516.

[6] Wan, V. C., Kim, M. S., Lee, S. Water vapor permeability and mechanical properties of soy protein isolate edible films composed of different plasticizer combinations. *J. Food Sci.* **2005**, *70*, E387.

[7] Seung, Y. C., Chul, R. Sorption characteristics of soy protein films and their relation to mechanical properties. Lebensmittel–Wissenschaft Technol. **2001**, *35*, 151-157.

[8] Ralston, B. E. & Osswald, T.A. Viscosity of soy protein plastics as determined by screw-extrusion through a capillary die. *Soc. Plast. Eng. Annu. Tech. Conf. Proc.* **2006**, 1479-1483.

[9] Huang, H. C., Chang, T. C., Jane, J. Mechanical and physical properties of protein-starch based plastics produced by extrusion and injection molding. *J. Am. Oil Chem. Soc.* **1999**, *76*, 1101-1108.

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