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LDPE-Soybean Seed Extrusion Process

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ABSTRACT

Low-density polyethylene (LDPE) contributes significantly to plastic waste accumulation due to its non-biodegradable nature. One promising approach to mitigate this issue is blending LDPE with biodegradable materials. In this study, LDPE was blended with soy-based bioplastic using a single-screw extrusion process with variations in barrel temperature, screw rotation speed, and bioplastic composition. The extruded pellets were subsequently molded into thin sheets and subjected to biodegradation testing using a soil burial method, as well as morphological characterization using scanning electron microscopy (SEM).

The experimental results indicate that extrusion parameters significantly influence the biodegradation behavior of LDPE–soy bioplastic composites. Taguchi analysis revealed that the optimal processing conditions were a barrel temperature of 95 °C, a screw speed of 50 rpm, and a soy bioplastic content of 20 wt%. Under these conditions, the composites exhibited the highest biodegradation performance. SEM observations showed the presence of bioplastic agglomeration and heterogeneous morphology due to uneven dispersion of the soy bioplastic phase within the LDPE matrix. These microstructural characteristics were found to contribute positively to the biodegradation behavior of the composites. The findings demonstrate that controlled extrusion processing is an effective strategy for producing partially biodegradable LDPE-based materials with enhanced environmental performance.

Key words: Biodegradation, bioplastic, extrusion, LDPE, SEM, soybean

1. INTRODUCTION

Plastics are indispensable materials in modern life and are extensively used in food packaging, beverages, and household appliances due to their high molecular weight, durability, and versatility. However, the widespread use of commodity plastics has led to serious environmental concerns, particularly related to waste accumulation, as most synthetic polymers are resistant to natural degradation processes [1]. One commonly used polymer is Low-Density Polyethylene (LDPE), which is characterized by its flexibility, toughness, airtightness, ease of reshaping, and excellent chemical resistance. Despite these advantages, LDPE is non-biodegradable, leading to long-term environmental persistence after disposal [2].

To address this issue, considerable efforts have been directed toward improving the environmental performance of LDPE by blending it with biodegradable or natural polymers [3]. The incorporation of bioplastics into LDPE matrices has been shown to enhance biodegradability while maintaining acceptable material properties [4]. Bioplastics are generally defined as plastics derived from renewable biological resources and/or capable of biodegradation under specific environmental conditions [5]. Based on their source materials, bioplastics can be classified into starch-based, cellulose-based, protein-based, and aliphatic polyester bioplastics [6].

Among protein-based bioplastics, soy protein has attracted significant attention due to its availability, renewability, and relatively low cost. Soybeans contain approximately 35% protein and 20% fat by dry weight, making them a promising raw material for bioplastic production [7]. In this study, soy protein–based bioplastics were blended with LDPE at various compositions to improve biodegradability while retaining the processability of thermoplastics. Previous studies have reported the successful blending of protein-based bioplastics with LDPE, demonstrating changes in morphology, mechanical properties, and degradation behavior [8][9]. Sabetzadeh et al. [10], reported that increasing the biopolymer content significantly affects particle distribution, with agglomeration occurring at higher starch concentrations. The blending of synthetic polymers and bioplastics can be carried out using several methods, including mechanical mixing, blending, and extrusion processes [11].

Extrusion is one of the most widely used processing techniques for thermoplastics and polymer blends. In this process, materials are heated above their melting point and conveyed by a rotating screw through a heated barrel, resulting in molten material that is shaped by a die or nozzle. Early developments in bioplastic processing demonstrated the feasibility of producing starch-based plastics using single-screw extruders at barrel temperatures of approximately 120–125 °C [12]. The screw plays a critical role in the extrusion process, functioning as a conveying, mixing, and shearing element. Elevated temperatures and friction within the barrel promote plastification and dispersion of the blended materials [13].

In this research, a single-screw extruder was selected due to its simpler geometry, widespread industrial application, and lower maintenance requirements compared to twin-screw systems [14]. The extrusion process is expected to promote homogeneous mixing of LDPE and soy-based bioplastics through controlled thermal and shear conditions. Previous studies have demonstrated that variations in extrusion parameters, particularly barrel temperature and screw speed, significantly influence the physical, mechanical, and structural properties of extruded bioplastics [15].

According to Lui and Peng [16], higher screw speeds tend to enhance biodegradability due to increased shear forces that improve polymer dispersion. Arbiantara et al. [17] further reported that shear intensity during extrusion affects molecular aggregation and intermolecular interactions in biodegradable plastic blends. Technological advancements in extrusion systems, such as improved barrel heating control, have enabled better processing of bioplastics with enhanced functional properties [18]. Additionally, extrusion temperature plays a critical role in determining degradation behavior; lower extrusion temperatures have been associated with increased biodegradation rates in certain biodegradable materials [19].

Based on the above background, the production of LDPE–soybean bioplastic pellets using an extrusion process with controlled temperature and screw speed represents a promising approach to developing partially biodegradable plastic materials. This study focuses on evaluating the effects of extrusion parameters—namely screw rotation speed, barrel temperature, and soy bioplastic content—on the biodegradability and blending quality of LDPE–soy bioplastic composites. The resulting specimens were characterized through biodegradation testing and morphological analysis using Scanning Electron Microscopy (SEM) to determine the degree of homogeneity and identify optimal processing conditions for producing LDPE–soy bioplastic blends.

2. METHODS

2.1 Material

The primary materials used in this study were Low-Density Polyethylene (LDPE) and soy-based bioplastic pellets. LDPE was used as the polymer matrix due to its good processability and mechanical stability. The soy bioplastic was produced by blending soy protein isolate, tapioca starch, and glycerol using an extrusion process, followed by oven drying, as reported in a previous study [3]. The resulting soy bioplastic was prepared in pellet form to ensure consistent feeding during the extrusion process.

Soy bioplastic pellets were obtained from the Material Laboratory, University of Jember. All materials were used as received without further chemical modification. The selection of soy protein–based bioplastics was motivated by their renewable origin, biodegradability, and compatibility with thermoplastic processing [7][20].

2.2 Bioplastic Preparation

This research employed an experimental method to investigate the effects of extrusion parameters on the properties of LDPE–soy bioplastic composites. The extrusion process involved blending LDPE with soy bioplastic pellets using a single-screw extruder. Three independent variables were examined: (i) barrel temperature, (ii) screw rotation speed, and (iii) soy bioplastic content in the LDPE matrix.

Table 1: Extrusion process variables and experimental levels for LDPE–soy bioplastic composites

Factor	Symbol	Parameter	Level 1	Level 2	Level 3
Barrel temperature	T	Extrusion barrel temperature (°C)	95	115	135
Screw speed	S	Screw rotation speed (rpm)	30	40	50
Composition	C	Soy bioplastic content (wt%) : LDPE (wt%)	0 : 100	10 : 90	20 : 80

The combinations of variables and their corresponding symbols are summarized in Table 1. The extrusion process was carried out using a single-screw extruder equipped with adjustable band heaters to precisely control barrel temperature. Single-screw extrusion was selected due to its simple design, stable operation, and widespread industrial application for thermoplastic blending [14][21].

Figure 1 illustrates the experimental workflow employed in this study. During extrusion, LDPE and soy bioplastic pellets were dry-mixed according to the specified composition and then fed into the extruder hopper. The molten composite exiting the die was cooled under ambient conditions and subsequently cut into small pellets. For further testing, the pellets were molded into thin sheets using a compression molding process and adjusted to the required dimensions in accordance with relevant testing standards [22].

Extrusion parameters such as temperature and screw speed were selected based on previous studies demonstrating their significant influence on polymer dispersion, interfacial bonding, and degradation behavior in biopolymer-based composites [23][3].

Raw Materials
(LDPE pellets + Soy bioplastic pellets)

↓

Pre-mixing (dry mixing based on composition C)

↓

Extrusion Process (Single-Screw Extruder)
- Barrel temperature (T): 95, 115, 135 °C
- Screw speed (S): 30, 40, 50 rpm
- Composition (C): 0, 10, 20 wt% soy bioplastic

↓

Pelletizing
(Cutting extrudate into bioplastic pellets)

↓

Compression Molding
(Forming thin bioplastic sheets)

↓

Characterization
- Biodegradation test (soil burial, mass loss)
- Morphological analysis (SEM)

↓

Data Analysis & Interpretation
(Process–structure–biodegradation relationship)

Figure 1: Experimental workflow for the preparation and characterization of LDPE–soy bioplastic composites

2.3 Biodegradation Test

The biodegradation behavior of the LDPE–soy bioplastic composites was evaluated using a soil burial method following ASTM D6003-96 guidelines. Compost soil was placed in polybags and plastic containers, and its acidity and moisture were measured using a three-way soil meter, with an average pH of approximately 6 and relative humidity (rH) ranging from 3 to 4.

Specimens were prepared by compression molding into square sheets with dimensions of 20 mm × 20 mm and a thickness of less than 1 mm [24][3]. Each specimen was buried at a depth of 10 cm in compost soil for different burial periods of 0, 5, 10, and 15 days. At the end of each burial period, specimens were carefully removed, cleaned, dried, and weighed using a digital balance to determine weight loss as an indicator of biodegradation.

For each burial condition, plastic containers with dimensions of approximately 8 cm in diameter and 15 cm in height were filled with soil to about 90% of their capacity. Small holes were made in the containers to allow air exchange and maintain aerobic degradation conditions. The biodegradation performance was assessed based on the percentage of mass loss over time, as commonly applied in soil burial studies of bio-based plastics [25].

2.4 Characterization

Morphological analysis of the LDPE–soy bioplastic composites was conducted using a Hitachi TM3000 Scanning Electron Microscope (SEM). SEM observations were performed to evaluate the dispersion and interfacial compatibility between LDPE and soy bioplastic phases, which are critical indicators of blending quality and material homogeneity [8][26].

Prior to SEM analysis, the molded bioplastic sheets were prepared and mounted on specimen holders. Imaging was carried out using an accelerating voltage of 15 kV. Micrographs were obtained at magnifications of 250× and 500× to capture surface morphology and particle distribution. The SEM images were analyzed qualitatively to assess the effects of extrusion parameters on the microstructural characteristics of the composites.

2.5 Experimental Design

The experimental design of this study was structured to systematically evaluate the influence of extrusion process parameters on the biodegradation behavior and morphological characteristics of LDPE–soy bioplastic composites. Three independent variables were considered: barrel temperature, screw rotation speed, and soy bioplastic content. Each variable was investigated at three predefined levels, as described in Section 2.2 and summarized in Table 1.

The selection of these parameters was based on previous studies indicating that material composition, thermal conditions, and shear intensity during extrusion play critical roles in polymer dispersion, interfacial bonding, and degradation behavior of biopolymer-based composites [23][3][21]. Screw speed was selected to represent different shear regimes, while barrel temperature levels were chosen to ensure adequate melting of LDPE without excessive thermal degradation of the soy-based bioplastic phase.

A factorial experimental approach was adopted to observe the individual and combined effects of the selected parameters. This approach enables a clear interpretation of process–structure–property relationships, which is commonly applied in polymer processing and extrusion-based composite studies [27][28]. Although no formal optimization algorithm was applied, the experimental matrix allowed for qualitative comparison of trends across parameter variations.

The primary response variables evaluated in this study were (i) biodegradation performance, assessed through mass loss during soil burial tests, and (ii) blending quality, examined through SEM-based morphological observations. The experimental design was intended to identify parameter combinations that promote improved biodegradability while maintaining acceptable material homogeneity. Similar parameter-driven experimental strategies have been successfully employed in studies involving extrusion of bioplastics and bio-filled polymer composites [29][30][31].

3. RESULTS AND DISCUSSION

The results of this study consist of biodegradation performance analysis using the Taguchi method and morphological observations of LDPE–soy bioplastic composites obtained through Scanning Electron Microscopy (SEM) at magnifications of 250× and 500×. The discussion focuses on the influence of extrusion parameters—barrel temperature, screw speed, and bioplastic composition—on the biodegradability and homogeneity of the resulting bioplastic pellets.

3.1 Biodegradation Test

The biodegradation performance of LDPE–soy bioplastic composites was evaluated using soil burial tests, and the experimental results were analyzed using the Taguchi method. The calculated mass loss values for each experimental run were processed using Minitab 19 software, and the results are summarized in Table 2.

Table 2: Results of biodegradation test

No	Control Parameter			Replica			Average
	T	S	C	1	2	3	
1	95	30	0	0,19	0,19	0,15	0,18
2	95	40	10	3,02	3,74	3,22	3,33
3	95	50	20	4,86	6,67	6,57	6,03
4	115	30	10	2,61	2,75	2,63	2,67
5	115	40	20	4,36	3,80	4,64	4,27
6	115	50	0	0.14	0,23	0,16	0,18
7	135	30	20	3,06	2,86	3,66	3,19
8	135	40	0	0,21	0,18	0,12	0,17
9	135	50	10	3,06	2,67	2,80	2,85

Table 3: Average response of S/N ratio to biodegradation test

Level	Temperature	Speed	Composition
1	3,48	1,08	-15,65
2	1,79	2,26	9,30
3	0,97	2,90	12,60
Delta	2,51	1,82	28,25
Rank	2	3	1

To identify the optimal combination of extrusion parameters, the Taguchi L9 orthogonal array was employed. The optimization criterion was based on the larger-is-better signal-to-noise (S/N) ratio, as higher mass loss indicates improved biodegradability. The average S/N ratios corresponding to each factor level are presented in Table 3.

Based on the calculated S/N ratios, the main effects plot was generated to visualize the influence of each parameter on biodegradation behavior, as shown in Figure 2. The S/N ratio plot indicates that barrel temperature, screw speed, and bioplastic composition all affect the biodegradation response, although with varying degrees of influence.

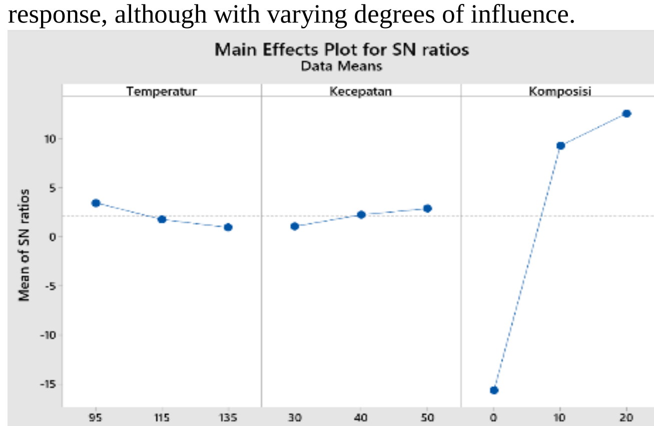

Figure 2: S/N ratio plot of biodegradation test

The optimal parameter combination was determined from the highest S/N ratio values and is summarized in Table 4. The results indicate that the optimal extrusion conditions for maximizing biodegradation are a barrel temperature of 95 °C (Level 1), a screw speed of 50 rpm (Level 3), and a soy bioplastic composition of 20 wt% (Level 3). These conditions suggest that lower processing temperatures combined with higher shear rates and increased bioplastic content promote enhanced biodegradation behavior.

Table 4: Result of best combination parameter level

Control factor	Level	Value
Temperature	1	95°C
Speed	2	50 rpm
Composition	3	20%

Table 5: ANOVA calculation of control factor on biodegradation test

Control factor	DoF	SS	MS	F	P
T	2	5,93	2,97	10,49	*Significant*
S	2	4,59	2,29	8,10	*Significant*
C	2	86,41	43,21	52,68	*Significant*
Error	20	5,66	0,28		
Total	26	102,59			

To evaluate the statistical significance of each control factor, an analysis of variance (ANOVA) was conducted, and the results are presented in Table 5. ANOVA was performed at a significance level of 0.05, with an F-table value of 3.40. The analysis shows that all three parameters—barrel temperature, screw speed, and composition—have F-values exceeding the critical F-value, indicating statistically significant effects on the biodegradation response.

Table 6: Percent contribution of each control factor to the biodegradation test

Control factor	Percent contribution
Temperature	5,78%
Speed	4,47%
Composition	84,23%
Error	5,52%
Total	100%

The contribution percentage of each parameter was calculated based on the sum of squares (SS) values obtained from ANOVA, as summarized in Table 6. The composition of soy bioplastic exhibits the highest contribution, accounting for 84.23% of the total variation, followed by barrel temperature (5.78%) and screw speed (4.47%). The relatively low error contribution (5.52%) indicates that the experimental results are reliable and that the selected control factors adequately explain the observed variability in biodegradation behavior [27].

The dominant influence of bioplastic composition highlights the critical role of soy protein–based content in enhancing biodegradation. Increased bioplastic content introduces more hydrophilic and biodegradable phases into the LDPE matrix, facilitating microbial activity and mass loss during soil burial. The influence of barrel temperature suggests that lower extrusion temperatures reduce thermal degradation of the biopolymer phase, preserving functional groups that are susceptible to biodegradation. Meanwhile, higher screw speeds increase shear forces during extrusion, promoting better dispersion of the bioplastic phase and improving interfacial exposure to the soil environment, which is consistent with previous findings in extrusion-based biopolymer studies [16][17][23].

Overall, the Taguchi and ANOVA analyses confirm that extrusion parameters significantly influence the biodegradation performance of LDPE–soy bioplastic composites, with material composition being the most critical factor. The identified optimal parameter combination provides a practical processing window for producing LDPE–soy bioplastic pellets with enhanced biodegradability while maintaining process stability.

3.2 Microstructure Observations

Figures 3 and 4 present SEM micrographs of LDPE–soy bioplastic composites processed at a screw speed of 40 rpm and a soy bioplastic composition of 20 wt%, with variations in extrusion barrel temperature. The observations were conducted at magnifications of 250× and 500× to evaluate particle dispersion, phase distribution, and interfacial characteristics within the composite matrix.

At both magnifications, the presence of soy bioplastic particles embedded within the LDPE matrix can be clearly observed. The micrographs reveal the occurrence of particle agglomeration in several regions, with an average agglomerate size of approximately 30 μm. These agglomerates appear as clustered domains that are unevenly distributed throughout the LDPE matrix, indicating incomplete dispersion during the extrusion process.

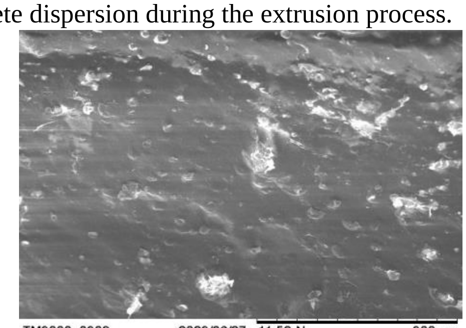

Figure 3: SEM micrograph of LDPE–soy bioplastic composite at 250× magnification

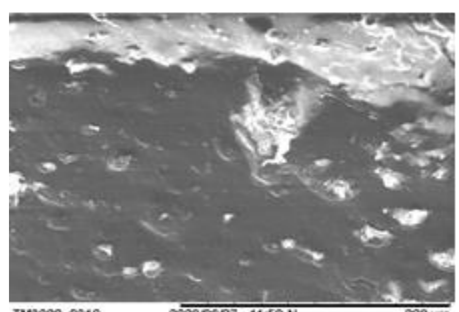

Figure 4: SEM micrograph of LDPE–soy bioplastic composite at 500× magnification

3.3 Discussion

The SEM observations demonstrate that the dispersion of soy-based bioplastic within the LDPE matrix is not entirely homogeneous, particularly at higher bioplastic contents. The presence of agglomerated regions suggests limited interfacial compatibility between the hydrophobic LDPE matrix and the hydrophilic soy bioplastic phase. This phenomenon is commonly reported in blends of synthetic polymers with starch- or protein-based bioplastics due to differences in polarity and intermolecular interactions [8][10].

Blends with lower bioplastic or starch content generally exhibit better particle dispersion, where phase separation between LDPE and the bioplastic phase is less pronounced. In contrast, higher bioplastic concentrations promote particle–particle interactions, leading to increased agglomeration and localized phase separation. Similar trends have been reported in previous studies involving LDPE–biopolymer blends processed by extrusion [9][24].

From a biodegradation perspective, the observed agglomeration plays a critical role in enhancing degradation behavior. The clustered soy bioplastic domains create localized regions that are more susceptible to microbial attack and moisture penetration during soil burial. Microorganisms preferentially degrade the biodegradable bioplastic phase, leading to the formation of voids and microcracks within the composite structure. As degradation progresses, these defects facilitate further fragmentation and mass loss, resulting in higher biodegradation values. This mechanism explains the strong correlation between increased bioplastic content, microstructural inhomogeneity, and higher mass loss observed in the biodegradation tests discussed in Section 3.1.

Furthermore, the influence of extrusion parameters on microstructure is consistent with the Taguchi and ANOVA results. Lower barrel temperatures help preserve the integrity of the soy bioplastic phase, while higher screw speeds enhance shear forces that partially improve dispersion but may not be sufficient to completely prevent agglomeration at higher bioplastic contents. Consequently, the optimal parameter combination identified in the biodegradation analysis (95 °C, 50 rpm, 20 wt% soy bioplastic) represents a balance between sufficient dispersion and the intentional presence of biodegradable domains that promote degradation.

Overall, the SEM analysis confirms that microstructural characteristics—particularly particle agglomeration and phase distribution—are key factors governing the biodegradation behavior of LDPE–soy bioplastic composites. The observed morphology supports the biodegradation trends obtained from Taguchi optimization and provides microstructural evidence for the dominant influence of bioplastic composition on degradation performance.

4. CONCLUSION

This study investigated the effects of extrusion parameters—barrel temperature, screw speed, and soy bioplastic content—on the biodegradation behavior and microstructural characteristics of LDPE–soy bioplastic composites. The results demonstrate that all processing parameters significantly influence biodegradability, with soy bioplastic composition being the dominant factor, contributing more than 80% to the overall variation in mass loss.

Taguchi optimization identified the optimal extrusion conditions as a barrel temperature of 95 °C, a screw speed of 50 rpm, and a soy bioplastic content of 20 wt%, which yielded the highest biodegradation performance. SEM analysis revealed that increased bioplastic content led to particle agglomeration and heterogeneous morphology within the LDPE matrix. These microstructural features promote microbial attack and facilitate mass loss during soil burial, thereby enhancing biodegradation.

The findings confirm that controlled extrusion processing can be used to tailor the microstructure and biodegradation behavior of LDPE–soy bioplastic blends. This work provides a practical processing window for producing partially biodegradable plastic pellets with potential applicability in environmentally friendly packaging and related applications. Future studies should focus on improving interfacial compatibility and evaluating mechanical performance to further expand the applicability of these composites.

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REFERENCES

[1] R. Stafford and P. J. S. Jones, “Viewpoint – Ocean plastic pollution : A convenient but distracting truth ?,” *Mar. Policy*, no. February, pp. 0–1, 2019, doi: 10.1016/j.marpol.2019.02.003.

[2] D. Hariadi, S. M. Saleh, R. A. Yamin, and S. Aprilia, “The Effect of Low Density Poly Ethylene (LDPE) Towards Plastic Oil Quality,” *Aceh Int. J. Sci. ang Technol.*, vol. 10, no. April, pp. 1–8, 2021, doi: 10.13170/aijst.10.1.17967.

[3] H. Arbiantara, “Analysis of Extrusion Process Parameters in The Manufacture of Bioplastic Pellets on Water Resistance and Biodegradation Test,” *Proc. 8th Int. Conf. Food, Agric. Nat. Resour. 2nd*

Int. Conf. Sustain. Ind. Agric. (IC-FANRes-IC-SIA 2023), p. (pp.197-210), 2024, doi: 10.2991/978-94-6463-451-8_18.

[4] K. S. Veethahavya, B. S. Rajath, S. Noobia, and M. K. B, "Biodegradation of Low Density Polyethylene in Aqueous Media," *Procedia Environ. Sci.*, vol. 35, pp. 709–713, 2016, doi: 10.1016/j.proenv.2016.07.072.

[5] K. G. Harding, T. Gounden, and S. Pretorius, "'Biodegradable' plastics: A myth of marketing?," *Procedia Manufakturing*, vol. 7, pp. 106–110, 2017, doi: 10.1016/j.promfg.2016.12.027.

[6] A. Shafqat, N. Al-zaqri, A. Tahir, and A. Alsalme, "Saudi Journal of Biological Sciences Synthesis and characterization of starch based bioplatics using varying plant-based ingredients , plasticizers and natural fillers," *Saudi J. Biol. Sci.*, vol. 28, no. 3, pp. 1739–1749, 2021, doi: 10.1016/j.sjbs.2020.12.015.

[7] M. Yamada, S. Morimitsu, E. Hosono, and T. Yamada, "International Journal of Biological Macromolecules Preparation of bioplastic using soy protein," *Int. J. Biol. Macromol.*, vol. 149, pp. 1077–1083, 2020, doi: 10.1016/j.ijbiomac.2020.02.025.

[8] D. Patel, S. D. Toliwal, and J. V. Patel, "Polymer-Plastics Technology and Engineering Morphology and Properties of Deoiled Cake (DOC) Isolated Mixed Proteins and Low-Density Polyethylene Blends Morphology and Properties of Deoiled Cake (DOC) Isolated Mixed Proteins and Low-Density Polyethylen," *Polym. Plast. Technol. Eng.*, no. November 2014, pp. 238–242, 2012, doi: 10.1080/03602559.2011.625375.

[9] T. J. Herald, E. Obuz, W. W. Twombly, and K. D. Rausch, "Tensile Properties of Extruded Corn Protein Low-Density Polyethylene Films 1," no. C, 2002.

[10] M. Sabetzadeh, R. Bagheri, and M. Masoomi, "Effect of Corn Starch Content in Thermoplastic Starch / Low-Density Polyethylene Blends on Their Mechanical and Flow Properties," *J. Appl. Polym. Sci.*, 2011, doi: 10.1002/app.

[11] M. Wang, L. Guo, H. Sun, and H. Kong, *Manufacturing Technologies for Biomaterials*. Elsevier Inc., 2018. doi: 10.1016/B978-0-12-801238-3.11027-X.

[12] F. H. Otey, R. P. Westhoff, and W. M. Doane, "Starch-Based Blown Films . 2," pp. 1659–1663, 1987.

[13] Sumardi, "Perancangan dan Fabrikasi Mesin Extrusi single screw," 2009.

[14] K. Prabha *et al.*, "Recent development , challenges , and prospects of extrusion technology," *Futur. Foods*, vol. 3, no. January, p. 100019, 2021, doi: 10.1016/j.fufo.2021.100019.

[15] G. H. Ryu, P. K. W. Ng, K. National, M. State, and E. Lansing, "Effects of Selected Process Parameters on Expansion and Mechanical Properties of Wheat Flour and Whole Cornmeal Extrudates Research Paper," vol. 53, pp. 147–154, 2001.

[16] W. Lui and J. Peng, "Effects of Feed Compositions and Screw Configurations on the Properties of Biodegradable Loose-Fill Extruded Foams," *Eng. Agric. Environ. Food*, vol. 1, no. 1, pp. 24–32, 2008, doi: 10.1016/S1881-8366(08)80010-9.

[17] H. Arbiantara *et al.*, "PENGARUH PROSES PENGADUKAN TERHADAP KARAKTER ADONAN DAN SIFAT BIODEGRADABLE PLASTIC [EFFECT OF THE MIXING PROCESS ON THE DOUGH CHARACTER AND THE PROPERTIES OF BIODEGRADABLE PLASTIC]," vol. 6, no. April, pp. 1–4, 2013.

[18] D. K. Dwinata, J N W Karyadi, D Y Susanti, A S Samodra, R S Mahanani and P. F. P. S. Rahmawati, "Physical characteristics of extrudate with treatment composition ratio of mixed corn grit-soybean flour and extruder barrel temperature Physical characteristics of extrudate with treatment composition ratio of mixed corn grit-soybean flour and extruder ba," *IOP Conf. Ser. Earth Environ. Sci.*, 2024, doi: 10.1088/1755-1315/1290/1/012009.

[19] R. Yue *et al.*, "Materials Science & Engineering C E ff ects of extrusion temperature on microstructure , mechanical properties and in vitro degradation behavior of biodegradable Zn-3Cu-0 . 5Fe alloy," *Mater. Sci. Eng. C*, vol. 105, no. January, p. 110106, 2019, doi: 10.1016/j.msec.2019.110106.

[20] A. Dey, M. M. Rahman, A. Gupta, N. Yodo, and C. W. Lee, "A Performance Study on 3D-Printed Bioplastic Pots from Soybean By-Products," 2023. doi: 10.3390/su151310535.

[21] H. T. Nguyen, J. Prochazka, Z. Studeny, and D. Dobrocky, "Effects of Extrusion Parameters on Filament Quality and Mechanical Properties of 3D Printed Pc/Abs Components," *MM Sci. J.*, vol. 2025-June, pp. 8453–8458, 2025, doi: 10.17973/MMSJ.2025_06_2025058.

[22] T. Lindriati and H. Arbiantara, "PENGEMBANGAN PROSES COMPRESSION MOLDING DALAM PEMBUATAN EDIBLE FILM DARI TEPUNG KORO PEDANG (Canavalia ensiformis L.) [Development of Compression Molding Process for Edible Films Production from Canavalia ensiformis (L.) Flour]," 2011.

[23] G. N. Wamuti, J. W. Mwangi, S. K. Karanja, L. Micke, and H. Zeidler, "Optimization of Extrusion Process Parameters of Recycled High-Density Polyethylene-Thermoplastic Starch Composite for Fused Filament Fabrication," *Open J. Compos. Mater.*, vol. 13, no. 04, pp. 69–86, 2023, doi: 10.4236/ojcm.2023.134006.

[24] G. Miranda *et al.*, "Abiotic and biotic degradations of a LDPE blend in soil of South Brazil landfill," *Iran. Polym. J.*, no. 0123456789, 2020, doi: 10.1007/s13726-020-00866-w.

[25] C. Lors, P. Leleux, and C. H. Park, "State of the art on biodegradability of bio-based plastics containing polylactic acid," *Front. Mater.*, vol. 11, no. January, pp. 1–14, 2024, doi: 10.3389/fmats.2024.1476484.

[26] E. M. H F Sangian *et al.*, "Study of SEM , XRD , TGA , and DSC of Cassava Bioplastics Catalyzed by Ethanol Study of SEM , XRD , TGA , and DSC of Cassava Bioplastics Catalyzed by Ethanol," *IOP Conf. Ser. Mater. Sci. Eng.*, 2021, doi: 10.1088/1757-899X/1115/1/012052.

[27] K. Krishnaiah and P. Shahabudeen, *Applied Design of Experiments and*. 2012.

[28] C. Hamzaçebi, "Taguchi Method as a Robust Design Tool," *Qual. Control - Intell. Manuf. Robust Des. Charts*, pp. 1–19, 2021, doi: 10.5772/intechopen.94908.

[29] M. Darsin *et al.*, "the Effect of 3D Printing Filament Extrusion Process Parameters on Dimensional Accuracy and Strength Using Pla-Brass Filaments," *J. Eng. Sci. Technol.*, vol. 18, no. 1, pp. 145–155, 2023.

[30] A. Dey, M. M. Rahman, N. Yodo, and D. Grewell, "Development of biocomposite filament for fused filament fabrication from soy hulls and soy protein isolate," *Mater. Today Commun.*, vol. 34, p. 105316, 2023, doi: https://doi.org/10.1016/j.mtcomm.2023.105316.

[31] M. A. S. Siddiqui, M. S. Rabbi, R. U. Ahmed, and M. M. Billah, "Biodegradable natural polymers and fibers for 3D printing: A holistic perspective on processing, characterization, and advanced applications," *Clean. Mater.*, vol. 14, no. August, p. 100275, 2024, doi: 10.1016/j.clema.2024.100275.