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Development and Characterization of Bioplastic Synthesized from Ginger and Green Tea for Packaging Applications

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Abstract: The world is suffering from heavy pollution because of synthetic petrochemical plastic used in our daily activities. A possible solution is the use of bioplastic synthesized from natural renewable resources. The present work investigates the development and characterization of polymer bioplastic using ginger tea and green tea to decrease the adverse effect of petrochemical plastic waste for versatile applications. Two kinds of bioplastic samples were produced with two types of tea, ginger tea and green tea, using glycerol, vinegar, starch, and water. SEM (scanning electron microscopy), FTIR (Fourier transformed infrared spectroscopy), mechanical (tensile), TGA (thermogravimetric analysis), DSC (differential scanning calorimetry), and time tests of bioplastic degradation analysis were carried out to evaluate the morphological, mechanical, and thermal behaviors of the synthesized tea bioplastics. The research result showed ginger tea bioplastic had a maximum tensile strength of 2.9 MPa and a minimum elongation of 7.46 mm. More than 78% of degradation occurred in ginger bioplastic within 30 days. Compatible thermal and morphological characteristics are also observed in the prepared bioplastic samples.

Keywords: bioplastic; ginger tea; green tea; environmental remediation; morphology

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1. Introduction

Composites regularly come full circle into lightweight structures, having great firmness and custom-made properties for applications, subsequently sparing weight [1]. Bio-composites are materials made from filaments (standard or engineered) and petroleum-inferred non-biodegradable polymers or biopolymers [2]. However, bio-composites inferred from natural plastics and fibers are eco-friendlier, hence they are among the most desired materials of the 21st century [3]. The non-renewability and non-biodegradability of petroleum resources, depletion of reliable wood products, environmental concerns, and increasing awareness of the carbon footprint are causing research to be directed into natural fiber-reinforced composites for new applications [4]. Due to waste disposal

problems and strong environmental regulations, a significant proportion of scientific studies have led to biodegradable eco-composite materials [5]. Composite bioplasticis identified as an emerging material for creating maintainable materials, primarily because of the total biodegradability of composite biodegradable plastic produced for different applications [6–8]. Biopolymer-based materials are necessary to convert into hybrid biopolymer composites to increase their mechanical and tribological properties [9–11]. Biopolymer materials are available at a low price, have excellent mechanical properties, and are biodegradable [12,13]. Starch has been gaining attention since the 1970s. Numerous endeavors have attempted to create starch-based polymers for moderating petrochemical assets and diminishing their natural effects [14]. However, starch-based materials have a few downsides, including long-term steadiness caused by water assimilation, maturing caused by retro degree, and destitute mechanical properties [15]. Plasticizers such as glycerol have allowed us to make improvements in the shelf-life and versatility of items in order to overcome these restrictions [16].

Yam starch bioplastic exhibits better toughness in comparison to small flexible potato starch bioplastic [17]. Additionally, it has exceptionally tall biodegradable properties, with conventional mechanical and thermal properties [18]. $Ca_2þ$ particles in a starch–water suspension with and without warming impact its physicochemical properties [19]. Starch–water suspensions warmed without $Ca_2þ$ delivered custard without kinematic consistency; this was reflected in the immaculate flexible behavior of the mechanical test [19]. In contrast, the closeness of divalent particles of $Ca_2þ$ in these suspensions prompts the arrangement of a hydrogel [20] with a far better mechanical quality, Young's modulus, water dissolvability, and contact point; this is accomplished with 4% energy natural product peel expansion, combined with 32 to 38 wt % glycerol from 80 to 120 rpm screw speed [21]. Its pliable quality confirms that the bioplastic of jackfruit starch, percent stretching, Young's modulus, and glycerol produce a film with great mechanical properties [22]. Starch is suitable because of its for low cost, availability, renewability, biodegradability, on-abrasiveness, and low density [22]. However, starch-based materials have a few disadvantages, including long-term steadiness caused by water assimilation, maturing caused by retro degree, and destitute mechanical properties [23]. Plasticizers such as glycerol have allowed us to make strides in the shelf-life and versatility of items in order to overcome these impediments [15]. Filler is the foremost successful strategy to extend this inclination [16]. Some cost-effective fortifications are natural renewable assets [24], lyocell [25], brief abaca [26], paper mash [27,28], jute [29], bamboo [30], microcrystalline cellulose [31], pineapple [32], Cordenka [33], flax [34], sisal [35], and kenaf [36]. PLA is an attractive prospect due to its, renewability, biodegradability, moo thickness, non-abrasiveness, and its moo-fetched quality [37]. A selection of studies on the mixing of PLA/starches [38] such as wheat starch, corn starch, and cassava starch [39] have been investigated.

Acidification, hydrolysis, and microbial fermentation are the most common chemical or biological processes used to make bioplastic from different natural resources such as vegetable oil, potatoes, corn, and wheat [40,41]. Starch is considered one of the most-utilized sources by researchers among natural resources. Starch is basically formed by amylase and amylopectin. The linear structure of amylase provides highly flexible and strong mechanical properties. However, the branched structure of amylopectin provides lower resistance to tensile strength and elongation properties [42]. Among natural resources, starch is inexhaustible, renewable, and has a low price [43]. Different types of tea are mixed with starch nowadays to improve the quality of bioplastics. They are biodegradable and can improve the properties of bioplastics. The literature shows several examples of the preparation of bioplastic from tea [44].

Ginger is a flowering plant that is around one meter tall. Its rhizome and roots are widely consumed as a spice and folk medicine. It is traditionally used as medicine for menstrual pain, osteoarthritis, migraine, rheumatoid arthritis, diabetes, cardiovascular disease, metabolic disorder, etc. in different parts of the world, especially in China and the Indian subcontinent [45,46]. It is also popular for cooking. Edible fresh ginger contains

85–95% moisture which is sensitive to microbial damage [47,48]. It is rich in phenolic and terpene compounds [49]. Additionally, it is bio-degradable and can be converted into compost.

Green tea is a kind of non-fermented beverage and is beneficial for the health of consumers. It contributes to one fifth of global tea production. It is rich in catechins, amino acids, minerals, alkaloids, and polyphenols, which have potential health benefits [50,51]. It dominates the consumer tea market in China [52]. Based on its production method, green tea can be divided into four categories of roasted, baked, sun-dried, and steamed [53]. It has resistance to oxidation, cancer, neuro-degeneration, bacteria, and inflammation [54,55]. In addition, green tea is biodegradable, easily biodegrades in nature and is converted into compost fertilizer.

This research paper intended to use renewable natural agricultural sources such as green tea and ginger for the production of bioplastics. The novelty of this work is that it used both ginger and green tea to synthesize bioplastic, which the previous researchers did not do. Moreover, tea is a naturally renewable resource and is abundant in many parts of the world. It has excellent biodegradable properties. Besides, tons of used teas which can be reused are thrown out every day. This work may be a good source of information for the synthesis of bioplastics in order to reduce the hazards and issues of conventional plastics.

2. Materials and Methods

2.1. Materials

The raw materials used in this research work are available in the local area and are renewable. Their collection was easy and affordable. The raw materials for this research, for example corn, ginger, white vinegar, and glycerol, were collected from the nearby local market. The corn and ginger were washed three times with distilled water and dried under the sun, followed by boiling and blending to obtain starch. Distilled water was collected from the environment lab of IUBAT. Green tea was supplied by the famous tea brand Isphahani Mirzapur tea. Other researchers also used similar materials in their research to fabricate bioplastic materials [56].

2.2. Fabrication of Bioplastic

Two different types of bioplastic samples were developed with ginger and green tea, with the intention of improving the different properties of starch-based bioplastics. The ingredients, such as corn starch, distilled water, white vinegar, and glycerin, were measured carefully with the help of a precise electronic balance before being mixed with ginger. The mixture was stirred with a magnetic stirrer with the application of heat to boil. Later, the mixture was placed on aluminum foil and allowed to cool naturally [57,58]. Bubbles were removed when they formed from time to time. The same procedure was followed for green tea as well. Here, some percentages of tea have been mixed with corn starch to improve the properties of corn starch-based bioplastics. The percentages of different ingredients are shown in Table 1.

Table 1. Composition of different ingredients used to fabricate the bioplastic samples.

Ingredient	Weight	Percent (%)
Corn Starch	60 gm	11.50
Distilled water	360 mL	69.30
White Vinegar	40 mL	7.70
Glycerol	40 gm	7.70
Ginger/Green Tea	20 gm	3.80

2.3. Characterization

2.3.1. Soil Burial Biodegradation Test

All the prepared bioplastics must be biodegradable, and as such a test on biodegradability must be performed. The samples were cut with dimensions of 50 mm × 30 mm × 3 mm for the soil biodegradation test. The humidity and pH of the soil was 7.6% and 6.5, respectively. Each sample was measured carefully with a precise electronic balance. Then, the samples were buried in the soil at a 10 cm depth. The samples were buried for 7, 15, and 30 days, and weights were measured again after removal from the soil, followed by drying. The biodegradation rate was calculated from the weight differences [59–61]. The following formula was used to measure the rate of degradation.

$$\textbf{Loss of weight \%} = (\mathbf{M_i} - \mathbf{M_f})/\mathbf{M_i} \times \mathbf{100\%}$$

Here, $\mathbf{M_i}$ = the initial mass and $\mathbf{M_f}$ = the final mass of the bioplastic sample in a dry condition.

2.3.2. Mechanical Test

Tensile property is a crucial factor for bioplastic materials to be used in different practical applications. It determines the usability of a material based on its load-carrying capacity. Tensile tests were performed at Poly Cable Industries, Munshiganj, Dhaka, using the CHUN YEN brand Universal Testing Machine Model No.: CY-6040A4. Estimating the force–distance data at a stain rate of 2 mm/min at room temperature, the tensile strength (TS) and elongation were determined from the stress–strain curves. Each experiment was performed three times and average data were considered. The specimens before and after the tensile test are illustrated in Figures 1a and 1b, respectively.

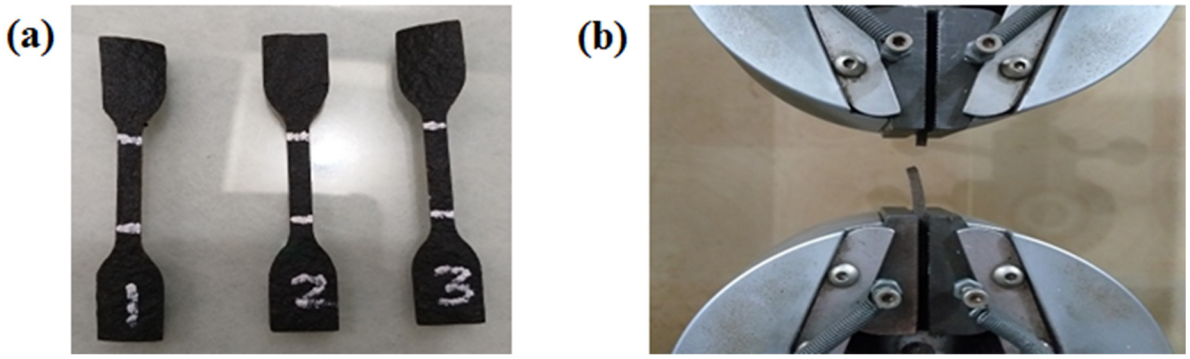

Figure 1. (**a**) Prepared samples for the tensile test and (**b**) a sample during the tensile test.

2.3.3. FTIR Analysis

The FTIR spectra analysis was carried out at the Centre for Advanced Research in Sciences (CARS) at the University of Dhaka, with Shimadzu machine Model No- IR Prestige-21. This analysis was performed on the samples of bioplastic to find the presence of different functional groups in the synthesized bioplastic samples. To identify the range of functional groups in relation to the chemical composition and physical state of the samples, this analysis is performed by an FTIR machine. The spectra were measured within the range of 500 cm^{-1} to 4000 cm^{-1}.

2.3.4. SEM Analysis

Surface morphology plays a crucial role in determining the properties of bioplastics, including mechanical and biodegradable bioplastics, to discover their application in various fields. The morphology of bioplastics and filler material distribution were analyzed by a scanning electron microscopy (sEm) analyzer. The microstructure of fabricated bioplastic with the arrangement of filler materials is clearly recognized using this method. The

samples were cut to dimensions of 10 mm × 10 mm × 3 mm for the test. The pictures were captured at 10 kV. SEM (Model: Hitachi SU-1510, made in Japan) was used to characterize the material surfaces in this study.

2.3.5. Thermal Analysis

Thermal property is an essential characteristic of a bioplastic material that is to identify its application at elevated temperatures. The thermal property was measured within a temperature range of 5 °C to 500 °C in a nitrogen environment, in which a 5 °C min^{-1} heating rate was maintained. A thermogravimetric analyzer (SDT650 Serial No. 0650-0180) was used to investigate the relationship between temperature, weight loss, and heat flow. After that, DSC and TGA measurement samples were acquired from a trial specimen for measuring HDT by cutting it perpendicularly from the glass mat. It should also be mentioned that the model weighing 39–55 mg was calculated for each test.

3. Results and Discussion

3.1. Mechanical Properties Analysis

Figure 2a–c, and Table 2 specify the mechanical properties of ginger tea and green tea bioplastic. Green tea provided the highest tensile strength. In the test, the ginger tea bioplastic was able to withstand 2.9 kgf loads, whereas green tea bioplastic was able to withstand a 2.7 kgf load. Ginger tea bioplastic showed a 2.9 N/mm^2 Young's modulus, and green tea bioplastic showed 2.1 N/mm^2 Young's modulus. Elongation was observed at 7.4 mm and 8.5 mm from ginger tea and green tea bioplastic samples, respectively. The maximum stress obtained from the samples prepared by ginger tea bioplastic and green tea bioplastic was 2.5 N/mm^2 and 2.6 N/mm^2, respectively. Ginger tea bioplastic and green tea bioplastic samples showed maximum strains of 37.3% and 42.5%. The incorporation of green tea enhances tensile properties [17]. The improvement in the mechanical properties of green tea bioplastic may be because of the higher cross-linking of bioplastics at lower mold temperatures [62]. The higher percentage of proteins and the thermal profile of the proteins present in green tea bioplastics because of this higher cross-linking act to improve its mechanical properties. However, increased heat treatment time improves the maximum stress while decreasing the maximum strain, thus making bioplastic stiffer [63]. The standard deviation, in fact, the error obtained in this research was ±2%.Table 2 shows the tensile properties of the bioplastic samples.

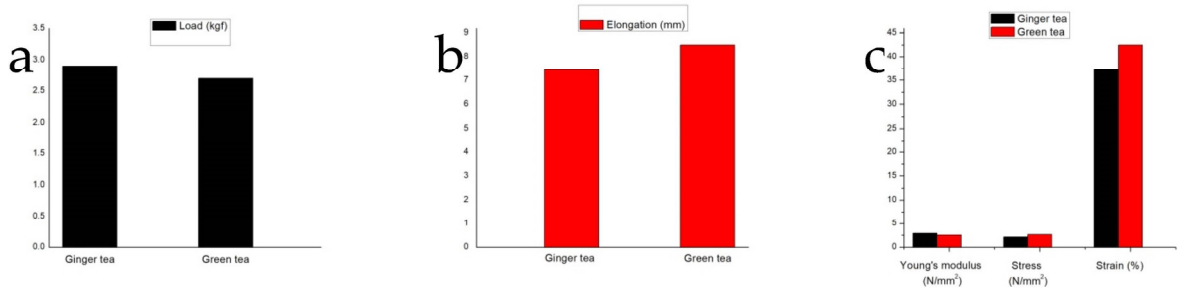

Figure 2. Mechanical properties of the prepared bioplastic samples (**a**) load, (**b**) elongation and (**c**) stress vs. strain curve.

Table 2. Tensile properties of different samples.

Sl. No.	Samples	Load (kgf)	Young's Modulus (N/mm^2)	Elongation (in mm)	Stress (N/mm^2)	Strain (%)
1	**Ginger Tea**	2.9	2.946	7.46	2.582	37.30
2	**Green Tea**	2.7	2.138	8.50	2.678	42.50

3.2. FTIR Analysis

The purified bioplastic was first characterized using Fourier-transform infrared (FTIR) spectroscopy. There were several major functional groups in the FTIR spectrum of the bioplastic., i.e., FTIR investigation has been carried out to compare the spectra of ginger tea and green tea bioplastics, as shown in the spectra displayed in Figure 3a,b. Both spectra show similar types of curves, as both of the samples were prepared from similar types of ingredients such as corn starch, distilled water, white vinegar, and glycerol. The only difference was the use of ginger tea in one sample and green tea in another sample. However, both ginger tea and green tea are organic and have similarities in chemical constituents. This is why both spectra show similar characteristics. The alcohol (O-H) stretching band is at 3317.56 cm^{-1}, which is shifted to 3305.99 cm^{-1} in green tea; this represents the aromatic phenolic compound of both ginger and green tea [64]. Wavenumber 1647.21 cm^{-1} is attributed to a hydroxyl group in ginger tea which shifted to 1645.28 cm^{-1} in green tea. Ginger tea has C-O stretching band at 1020.34 cm^{-1} which shifted to 1022.27 cm^{-1} in green tea. The sample prepared with tea contains strong stretching thiocyanate at 2152 cm^{-1}, which is not available in the sample prepared with ginger [65]. In addition, the sample prepared with ginger tea contains a medium stretching alcohol O-H band at 3725 cm^{-1} of the gingerol [66]. The different functional groups present in the bioplastics are shown in Table 3.

Table 3. Band assignment of ginger tea and green tea bioplastics.

Sl. No.	Functional Group	Wave Number Literature (cm^{-1})	Ginger Tea	Green Tea
1	**O–H stretching**	3600–3300 [50]	3313.47	3307.92
2	**C–H stretching**	2800–3000 [67]	2929.87	2929.87
			2860.43	2860.43
3	**C=O band**	1743 [68]	1743.65	1743.65
4	**OH hydroxyl groups bending**	1580–1700 [69]	1647.21	1645.28
	CH_2vibration bending	~1450 [70]	1452.4	1450.47
5	**C–O–C asymmetric stretching**	1149, 1151 [70]	1151.5	1151.5
6	**C–O stretching**	1200–800 [50]	1020.34	1022.27
	C–O–C ring vibration of carbohydrate	920, 856 [50]	923.9	923.9

3.3. Surface Morphology Analysis

The surface microstructure of the ginger tea bioplastic was examined with SEM analysis, and the results are displayed in Figure 4. Analyses of the ginger tea bioplastic's composite surface reveal that the bioplastic composite has sporadic character, including flaws in edges and grooves [71]. The SEM image shows that the ginger tea bioplastic surfaces are exposed to air (which is undesirable), with a few grooves and closer non-gelatinized granules [72]. The surface structure affects the tensile property of the bioplastic [69]. This surface is no more compatible than morphologies with fewer voids and cracks, and is associated with poor interfacial attachment [73]. Some micropores are visible in the micrographs and may interact with the microorganism available in the soil, accelerating the biodegradation process [74].

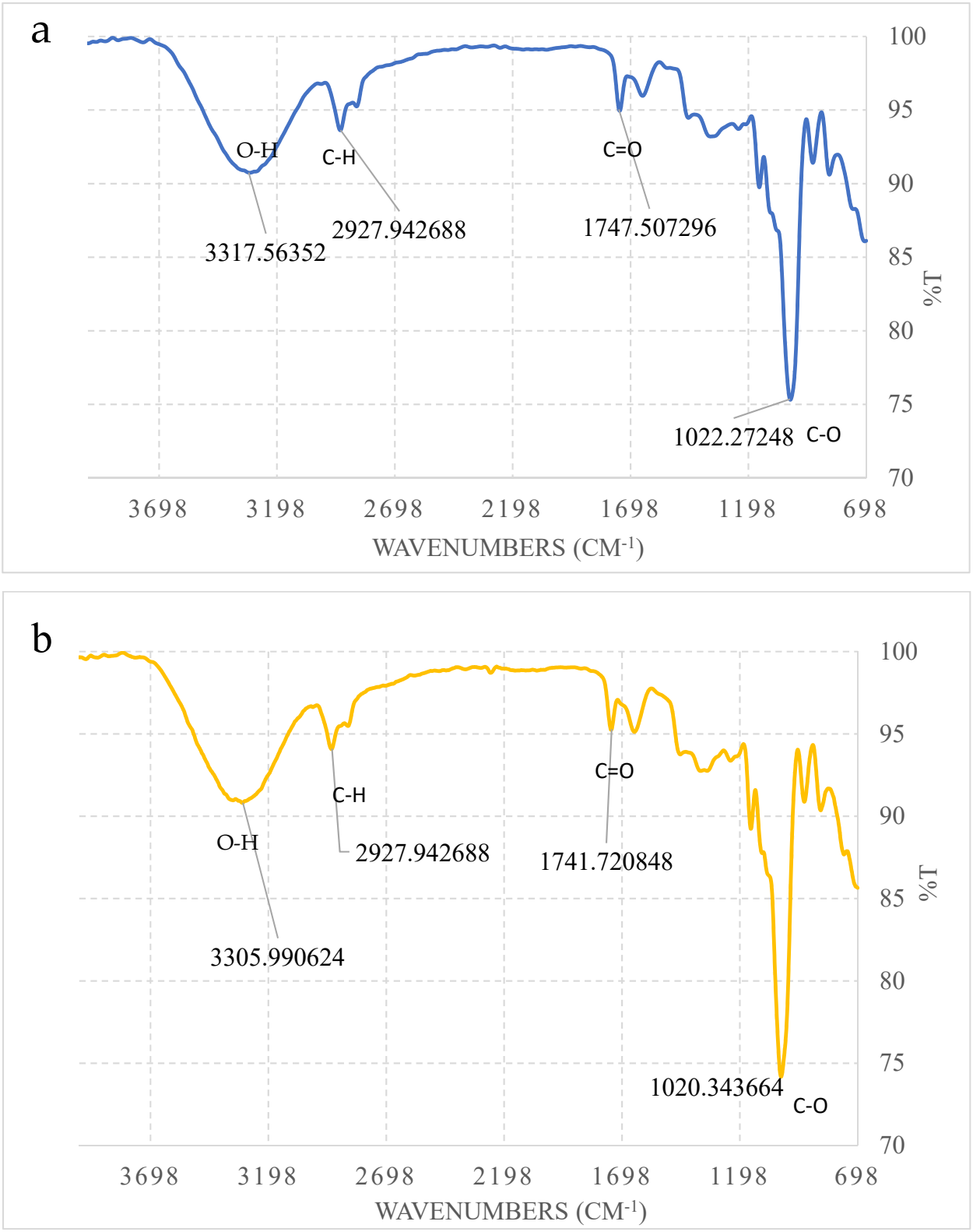

Figure 3. FTIR spectra of the prepared bioplastic samples (**a**) ginger tea and (**b**) green tea.

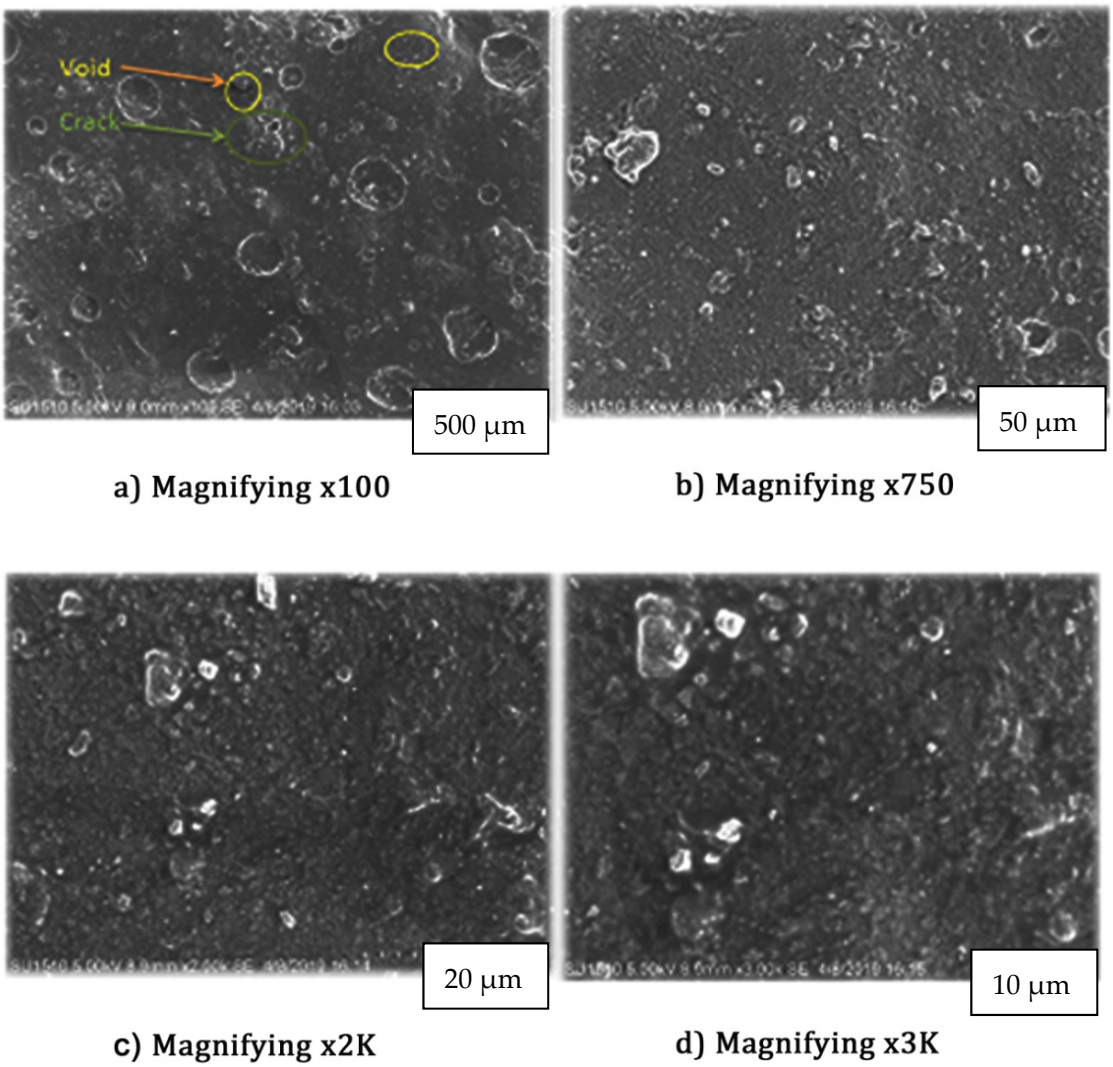

Figure 4. SEM photograph of ginger tea bioplastic at (**a**) 100×, (**b**) 750×, (**c**) 2000× and (**d**) 3000×.

The water evaporation during blend preparation, either by heating or in combination with mechanical stress and the lack of interface adhesion, causes void formation [75]. The smaller crack propagation of ginger tea bioplastics thus showed no better bonding between the components. The mechanical strength will be lower due to crack and void propagation from the solid particles [76].

Figure 5 shows the surface microstructure of green tea bioplastics using SEM analysis. Analyses of green tea-based bio-polymer surfaces seemed to uncover where an irregular structure existed. There are no cracks in the green tea bioplastics, but small and large air gaps are visible [77]. Because the *Camellia sinensis*(raw material of green tea) leaves and buds fibers are present in green bioplastics, an air gap has been created. Due to the air gap, mechanical strength will be lesser in these areas [78].

Finally, we can say that no void or crack was found in green tea bioplastic. The surfaces are filled with air gaps for both of the samples, with the presence of foreign particles.

3.4. Thermal Properties Analysis

A TA-Instrument SDT650 was used to examine the TGA and DSC analysis of the synthesized bioplastics. The specimen weight was within the range of 39–55 mg, and the heating rate was 5 °C per minute within the range of ambient to 500 °C temperature.

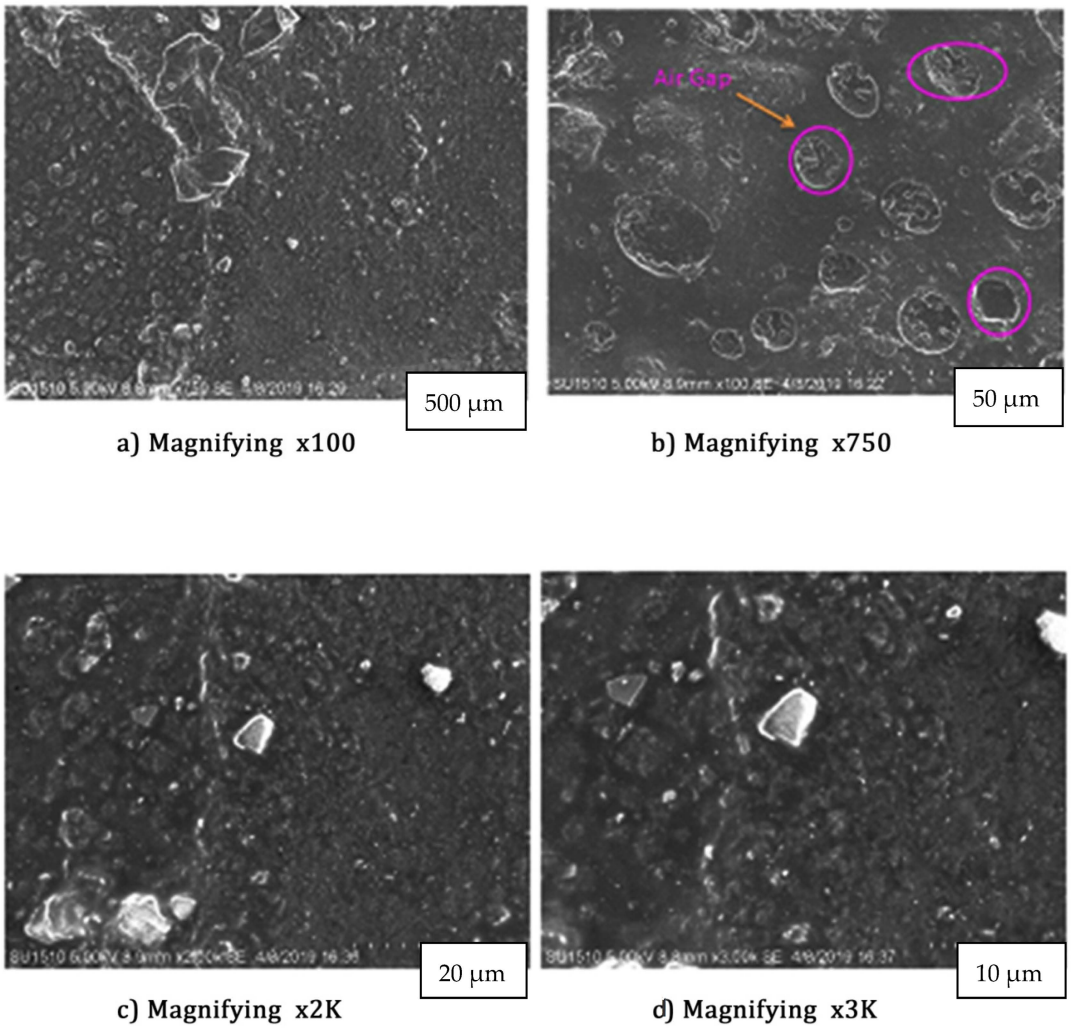

Figure 5. SEM photograph of green tea bioplastic at (**a**) 100×, (**b**) 750×, (**c**) 2000× and (**d**) 3000×.

3.4.1. TGA Analysis

Thermogravimetric analysis of the ginger tea bioplastic's decomposition profile is shown in Figure 6.Initially, the mass of the green tea bioplastic sample was 39 mg and the mass of the ginger tea bioplastic was 47 mg, which was the 100% weight for both of the samples. With the increase in temperature, weight decreased for both samples due to degradation. The TGA bioplastic composite indicates two stages of degradation. In the first step, 50–220 °C, the dissipation of moisture content may occur in the ginger tea bio-polymer, and this happened between 235–385 °C, which demonstrates the thermal deterioration of ginger tea bioplastics. The ginger was completely decomposed at 390 °C. In between temperatures of 25 and 100 °C, almost 5% of the weight is lost due to moisture evaporation [79,80]. At 350 °C, temperature pyrolysis of cellulose occurs, leaving only 10% of the weight of the samples [81,82].

It is well known that starch degrades at around 275 °C. In the primary step, 73–229 °C, the moisture was contained via evaporation in green tea bioplastic. In the second stage, between 250–396 °C, the thermal decomposition of green tea bioplastics was indicated.

Finally, the decomposition profiles of ginger tea bioplastic and green tea bioplastics are shown in Figure 7. Here, almost 50% of weight loss occurs around 265 °C for ginger and green tea bioplastics. After that temperature, a rapid weight loss is observed, and at around 290 °C, both samples lost more than 80% of their weight. Nurul et al. [83] also mentioned in the literature that in the case of yam and potato bioplastics, 50% of weight loss occurs between 250 °C and 310 °C, and at around 350 °C, more than 90% of their

weight is lost. The decomposition temperature of ginger tea bioplastic is higher than that of green tea bioplastic. It also indicates that green tea bioplastic has more excellent heat stability compared to ginger tea bioplastic. The summarized TGA test results are displayed in Table 4.

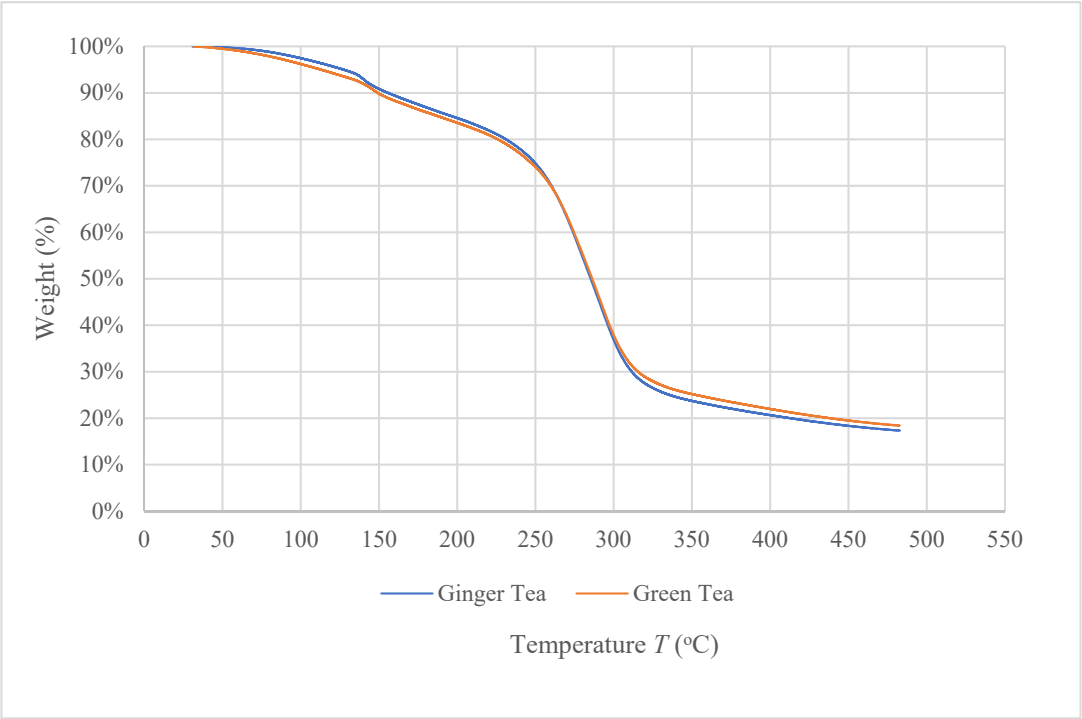

Figure 6. TGA analysis curve of the prepared bioplastic samples.

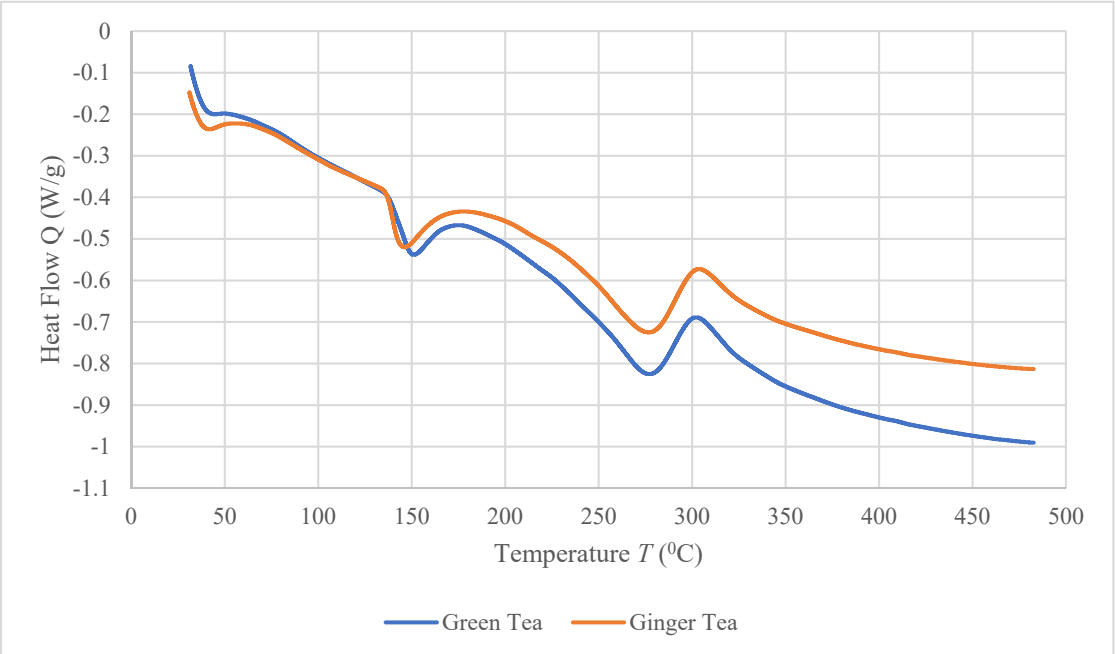

Figure 7. DSC analysis curves of the developed bioplastics samples.

Table 4. TGA test results of bioplastics samples.

Sl. No.	Sample	First Step	Second Stage
2	**Ginger Tea Bioplastic**	50–220 °C	235–385 °C
3	**Green Tea Bioplastic**	73–229 °C	250–396 °C

3.4.2. DSC Analysis

A differential scanning calorimetry graph of the ginger tea and green tea bioplastic decomposition profiles is seen in Figure 7. Here, the melting point T_m and glass transition temperature T_g point of these bioplastic samples are shown. Ginger tea bioplastic has a glass transition temperature range of 48–51 °C (approximate), a melting point of 276 °C, and a crystallization temperature of 304 °C. Green tea bioplastic has a glass transition temperature range of 49 °C to 52 °C (approximate), a melting point of 275 °C, and a crystallization temperature of 303 °C. Ginger tea bioplastic significantly shifted the glass transition temperature T_g. As T_g is above room temperature, glass-like behavior in strength, stiffness, and brittleness can be observed in the developed bioplastic samples [18]. The melting point T_m of the bioplastic was affected considerably in the presence of ginger tea. Initially, low heat flow is observed from the ginger tea bioplastic compared to the green tea bioplastic, but at higher temperatures, low heat flow is observed in the green tea bioplastic compared to the ginger tea bioplastic. This indicates that green tea bioplastic is more stable at a lower temperature than ginger tea bioplastic, and ginger tea bioplastic is more stable at a higher temperature than green tea bioplastic. Ginger tea has a high gelatinization temperature because of its constituents, such as higher lipid and protein content. The functional properties of starch, for example, can change with passing properties and can be charged with lipid complexes [17]. The addition of green tea decreases the phase transition temperature and decreases thermal stability [84]. However, significant changes in properties can be observed from the prepared samples, with a change of 1 °C. A summary of the DSC results is presented in Table 5.

Table 5. DSC test results of bioplastics samples.

Sl. No.	DSC Test (Sample)	Glass Transition Point T_g (°C)	Melting Point Temp T_m (°C)	Crystallization Temperature (°C)
2	**Ginger Tea bioplastic**	50	276	304
3	**Green Tea bioplastic**	49	275	303

3.5. Soil Burial Biodegradation Analysis

The soil burial test's degradation rate is measured from the weight differences before and after degradation. Figure 8a,b shows the samples before and after the degradation at different time intervals. From the obtained data, we can clearly observe that the biodegradability increases with the increase in time. It can also be observed that the sample containing ginger is more biodegradable compared to the samples containing green tea. This is because of the higher biodegradability properties of ginger. Both the samples followed linear biodegradation, which is in accordance with pseudo-zero-order kinetics in reaction rates and constant [85]. The rate of biodegradation was less initially because the microorganisms available in the soil were adapted to the samples and required adaptation time [86]. The biodegradation increased after 1 week for both of the samples, due to CO_2 production. Bingxue Jiang et al. [87] synthesized and characterized corn starch-based bioplastic for reinforcing eggshell powder. A soil biodegradation test was performed for 3 weeks and a maximum of 58.25% degradation was obtained. After 30 days of observation, it can be seen that the bioplastic samples prepared with ginger tea are far more biodegradable than green tea bioplastic. Ginger is a highly bioactive product because of its constituents, such as monoterpenes, sesquiterpenes, diterpenes, vanilloids, and flavonoids, which make

it highly biodegradable and increase the biodegradability of any product when they are mixed in [88,89]. Considering the biodegradability test, both bioplastics deteriorated very rapidly in relation to weight and quality, and are characterized as biodegradable materials. Table 6 compares the obtained biodegradable data with the data available in the literature.

3.6. Comparative Analysis

Green tea bioplastic showed better mechanical properties with 2.678 N/mm^2 tensile strength and 42.5% tensile strain. The glass transition temperature for Ruhul [68] was 66.8 °C, and for ginger tea bioplastic (present study) is 63 °C, which is higher than the present study. However, the melting temperature is higher in the present study. The thermal decomposition (50% of weight loss) is comparatively low in the mentioned previous study, and high in the present study, which is shown in Table 6. This investigation demonstrates that green tea bioplastic had improved physicochemical and thermal properties compared with others mentioned in current and previous studies. In the soil biodegradation test, a maximum of 78% degradation was obtained after 30 days of burial. Ginger bioplastic showed a higher rate of biodegradation compared to tea bioplastic because ginger is more biodegradable. This study may be compared with the studies of other researchers available in the literature (Table 7).

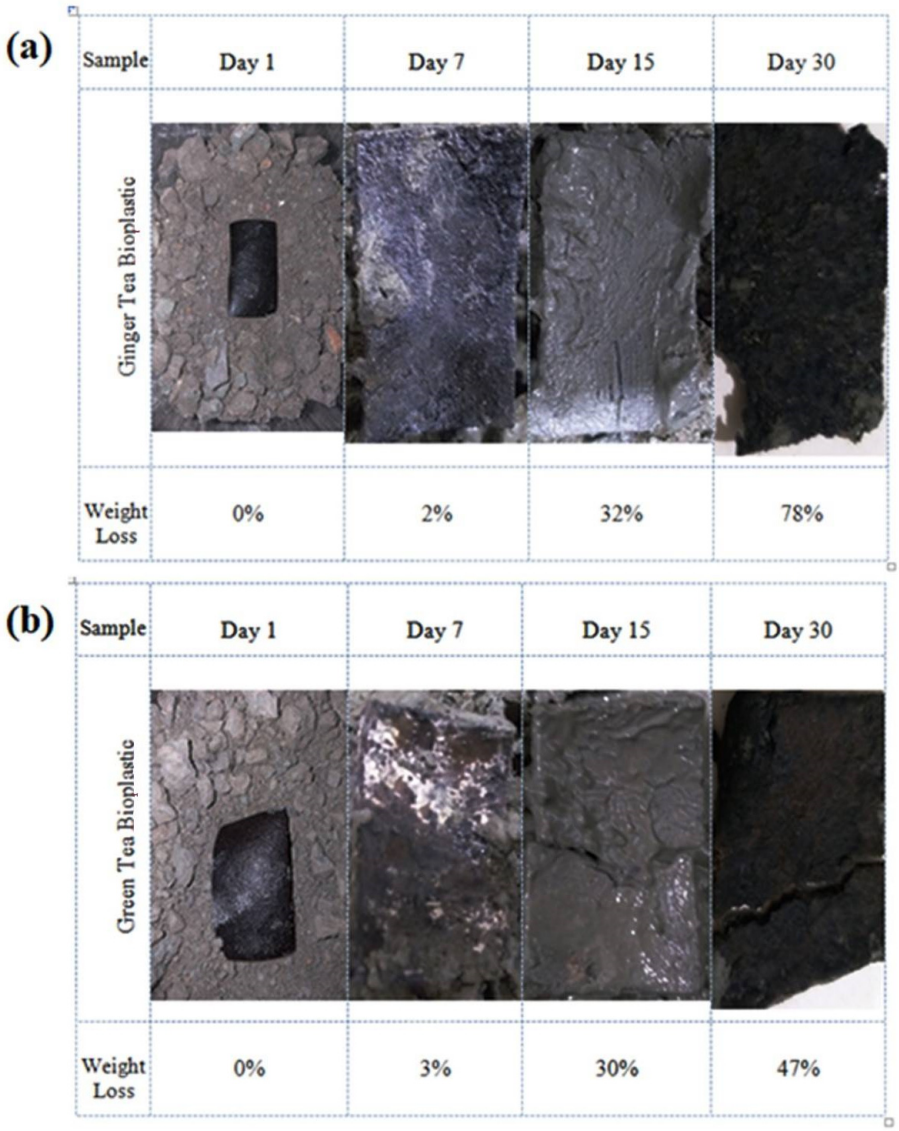

Figure 8. Bioplastic samples before and after biodegradation test synthesized by (**a**) ginger tea and (**b**) green tea.

Table 6. Biodegradation of different bioplastic samples found in the literature.

SL.	Degradation Medium	Weight Loss (%)	Time (Days)	References
1	Soil	100	4	[90]
2	Water	100	25	[91]
3	Soil	70.3	15	[17]
4	Sea water	39	30	[72]
5	Soil	50	10	[92]
6	Soil	69.29	45	[78]
7	Aerobic conditions in aqueous medium	86.8	68	[93]
8	Simulated environments	20	120	[94]
9	Soil	78	30	This work

Table 7. The comparative investigation of different kinds of tea bioplastics and relative research.

Sl. No.	Test/Analysis	Starch Bioplastic	Composite Bioplastic			Present Study	
		Previous Study [71]	Previous Study [80]	Previous Study [76]	Previous Study [56,74]	Ginger Tea	Green Tea
1	Tensile Strength (Mpa)	3.55	3.95	3.86	1.92	2.9	2.7
2	Elongation (%)	88.1	62.5	62.7	10.1	37.3	42.5
3	Glass Transition Temperature (T_g)	57.2 °C	66.8 °C	35.3 °C	—	63 °C	60 °C
4	Melting temperature (T_m)	297 °C	303 °C	136.6 °C	—	276 °C	275 °C
5	Thermal decomposition (50% of weight loss) °C	291 °C	303 °C	—	310 °C	285 °C	287 °C
6	Biodegradibility	64%	81%		60%	78%	47%

4. Conclusions

This research focused on bioplastics developed from natural ingredients. Tensile and thermal property analysis was carried out on bioplastics prepared from ginger tea and green tea. Green tea bioplastic was found to be much more durable, with higher strength and reduced elongation. Morphological analysis indicates that green tea bioplastic has a better consistent surface finish compared to ginger tea bioplastics. No voids or cracks were found in the green tea bioplastics, and fewer voids and cracks were also observed with ginger tea bioplastic. No chemical changes have been found in the tea bioplastic. As a result, all peaks appeared in the same manner for all specimens. DSC curves showed that the melting temperature (T_m) and glass transition temperature (T_g) of the utilized tea bioplastic and ginger tea bioplastic appeared at an inclination higher than other tea bioplastics. TGA demonstrated that ginger tea bioplastics have better thermal sustainability than green tea bioplastics. Soil burial biodegradation tests have been carried out for all prepared bioplastics. All tea bioplastics were found to be highly biodegradable. The results suggest that the developed bioplastics can be used in packaging applications.

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