

Research Article

Commercialization of Agar-based Bioplastic for Daily Use

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Abstract: Plastic consumption has severely threatened the survival of living creatures and the environment. Agar is seen as a commodity that might be novel in international trade if given enough study and consideration. It also can be found abundantly in Malaysia and obtained quickly. Thus, agar was chosen as the primary ingredient to create a biodegradable plastic. Sample C is the best agar-based bioplastic sample in this study since it has the highest value for every tested parameter. Eggshell-containing sample C exhibits the maximum applied strength of 0.037 MPa, biodegradability of 83.48% and water absorption of 29.78%. Currently, the potential commercialization of agar-based bioplastic is focused on the food and agriculture sector and the community. Food wrappers, polybags, and bioplastic as a replacement for conventional plastic are primarily intended for the food and agriculture sector, whilst the “DIY Bioplastic Kit” is aimed at the public. With its focus on the concept of a lab in a box, the bioplastic kit purposefully focuses on the idea of a self-contained laboratory to raise community awareness of environmental care via the 5R concept. Students may express their creativity and make personalized bioplastic goods by utilizing this kit to make their own bioplastic using agar as a basis.

Keywords: biodegradable bioplastic; plastic pollution; eco-friendly



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1. INTRODUCTION

Plastic bags, ubiquitous in our modern lives, have become emblematic of convenience and affordability. They have revolutionized how we carry groceries, transport belongings, and package goods. Plastic bags, primarily made from petroleum-based polymers such as polyethylene, polypropylene, and polyvinyl chloride, have gained immense popularity due to their affordability and durability, undeniably making daily life more convenient.

However, beneath their apparent utility lies a darker truth that has come to haunt our environment and human health due to plastic pollution. Their lightweight nature makes them particularly prone to windblown dispersal, contributing to the widespread scattering of plastic debris in urban and natural environments. The proliferation of plastic bags and their subsequent disposal has

triggered a global environmental crisis that poses a grave threat to ecosystems, wildlife, and human well-being. About 19-23 million tonnes of plastic waste has leaked into the ocean ecosystem (UN Environment Programme, n.d.) and according to the article published by The Star, Malaysia accumulated 73098 metric tonnes of plastic waste and has become one of the biggest contributors of plastic pollution in the ocean (Put More Focus on Reducing, Reusing Plastic instead of (Recycling, Say Experts, 2023).

Many preventive measures have been taken to reduce the plastic waste piled up from year to year, such as recycling programmes, single-use plastic bans (Excell, 2021), utilization of plastic waste for road construction (Gunjan et al., 2021) and many more. However, it is important to solve the problem from the root, the plastic itself. As we know, plastic takes a long time to degrade due to the elements and molecular structure they mainly comprise, such as hydrogen and carbon, which take a long time to degrade (Ng et al., 2023).

To overcome this issue, scientists and researchers are trying to develop a product that can substitute conventional plastic or at least reduce plastic degradation duration by creating a bioplastic. A few terms and definitions need to be understood about bioplastic. Bioplastic is made up of biological materials and renewable materials, and they may be degradable or may not be degradable. At the same time, Bio-based plastic refers to plastic made up entirely or partially from renewable carbon sources such as plant matter (Atiwesh et al., 2021).

Thus, this research aims to create or develop a biodegradable bio-based plastic made from agar-based, which has almost similar characteristics and durability as conventional plastics. Besides that, creating a self-contained laboratory with the concept of a lab in a box called the "DIY Bioplastic Kit" to provide awareness to the community about environmental care through the 5R concept also became our second objective of this research.

2. LITERATURE REVIEW

Bioplastics are materials derived from renewable sources, such as plants, algae, or bacteria, as opposed to conventional plastics produced from fossil fuels. In recent years, they have gained significant attention as a potential solution to the environmental issues associated with plastic waste and resource depletion. This can be seen by the statistic that has been published by Statista Research Department (2023), where the statistic of bioplastic production has increased globally from 2.2 million metric tons in 2022 to 2.4 million metric tons in 2023, and it is expected to reach 6.3 million metric tons by 2027.

Several renewable sources have been used as a base to develop the bioplastic. The main raw material for bioplastic production comes from plant sources such as sweet potato, corn starch, wheat and cellulose derivatives (Angeeleena et al., 2012). However, the usage of plant sources as the main based for bioplastic has its drawbacks as it affects the human food chain as the plant is one of the food resources for humans and animals, and it is time-consuming as the plant takes time to grow (Thiruchelvi et al., 2020).

Besides that, bacteria are also used to produce bioplastic, as most bacteria contain a chemical that has properties similar to polypropylene, which is known as intracellular PHA granules in their cells as the energy and carbon reserves (Verlinden et al., 2007). *Bacillus megaterium*, *Klebsiella aerogenes* recombinants and *Pseudomonas aeruginosa* are among the bacteria used to produce bioplastic as they contain high content of PHA (Zhang et al., 1994; Mirtha et al., 1995; Eggink et al., 1995 as cited in Angeeleena et al., 2012). Using bacteria as a base for bioplastic has limitations, such as the need to cultivate at specific conditions, special apparatus and infrastructure (Angeeleena et al., 2012).

Thus, to overcome this issue, algae is used as the source of raw material, and it can be divided into subclasses: microalgae and macroalgae. Spirulina dregs, one of the microalgae species, is used to produce the bioplastic. However, an issue has occurred due to the difficulty of harvesting that particular species (Thurmund, 2010, as cited in Angeeleena et al., 2012). Seaweed, known as macroalgae, has more potential to become a based of bioplastic as they are highly abundant, cost-effective and do not need airable land or specific condition to cultivate (Angeeleena et al., 2012). In addition, bioplastic made from seaweed can easily biodegrade for about one or two months, and they do not degrade into microplastic like conventional plastic, which is naked to the human eye (Lim et al., 2021).

Seaweed can be divided into three main species, which are green seaweeds (Chlorophyta), brown seaweeds (Pheophyta) and red seaweeds (Rhodophyta) (Lim et al., 2021). Alginate, carrageenan, and agar are the seaweed derivatives used in bioplastic making, as they can form a film with excellent properties (Lim et al., 2021). Agar is a type of polysaccharide that can be found in most red seaweed families such as Gracilariaceae and Gelidiaceae, and it is a hydrophilic colloid which helps it to form a gel texture film when cooling a hot aqueous solution (Hii et al., 2016). Utilized agar as a main raw material of bioplastic is an advantage for Malaysia as Gracilaria species can be found abundantly, especially on the west coast of Peninsular Malaysia (Hii et al., 2016).

3. METHOD & MATERIAL

Table 1. List of materials.

SAMPLE A	SAMPLE B	SAMPLE C	SAMPLE D
Without Addition of Vinegar and Eggshell	Addition of Vinegar	Addition of Eggshell	Addition of Vinegar and Eggshell
89 ml tap water 2 g agar powder 0.33 g gelatine 3.5 ml glycerol	89 ml tap water 2 g agar powder 0.33 g gelatine 3.5 ml glycerol 0.5 ml vinegar	89 ml tap water 2 g agar powder 0.33 g gelatine 3.5 ml glycerol 2.5g eggshell powder	89 ml tap water 2 g agar powder 0.33 g gelatine 3.5 ml glycerol 0.5 ml vinegar 2.5 g eggshell powder

Four beakers were labelled with A, B, C and D. Each 89 mL of tap water was poured into four different beakers. All beakers were heated under low heat on the hot plate. 0.5 ml vinegar was poured into beakers B and D. 2.5 g eggshell powder was added into the beakers C and D. The mixture in beakers B, C and D were stirred. Then, 2 g agar powder, 0.33 g gelatine and 3.5 ml glycerol were added into all beakers. A few drops red food colouring was added into the mixture. The mixture in each beaker was stirred until the colour blends with the solutions and become slightly viscous. Then, each mixture was poured into four different mold and let them dry overnight. The bioplastics were peeled carefully after being fully dried. Bioplastics from each sample A, B, C and D were used for testing such as tensile strength, biodegradability, and solubility test. The surplus bioplastics from each sample can be cut and stick into desired product.

4. FINDINGS

4.1 Tensile Strength

The tensile strength of bioplastic was test by using a Universal Testing Machine (UTM). Each bioplastic film is cut into 40 x30 mm rectangle shape. The samples are placed between the two jaws and clamped to perform the tension test. After placed the sample in its right position, the jaws are pulled apart to apply tension to the sample. The tension is applied to the sample until it reaches the fracture point. The result of the test is shown in the Table 2 below.

Table 2. Data of tensile strength.

Sample	Strength (MPa)	Toughness
A	0.024	0.042
B	0.005	0.001
C	0.037	0.002
D	0.029	0.002

From the result, sample C shows the highest value of strength applied, which is 0.037 MPa followed by samples D, A and B which are 0.0029 MPa, 0.024 MPa and 0.005 MPa respectively before it reaches its fracture point.

4.2 Biodegradability Test

The biodegradability test is performed by cutting same-sized pieces of each sample and labelled accordingly. Each sample is weighed and the initial mass is recorded before it is deposited in containers filled with soil, making every surface of the bioplastic piece is buried in the soil. After 14 days, each sample is taken out and weighed. The final mass of each sample is recorded, and the mass loss percentage is calculated and recorded in Table 3 below:

Table 3. Data of biodegradability test.

Sample	Initial mass (g)	Final mass (g)	Mass Loss Percentage (%)
A	0.0468	0.0353	75.49
B	0.0483	0.0162	66.38
C	0.0466	0.0077	83.48
D	0.0448	0.0369	82.36

The result indicated that samples C with 83.48% and D with 82.36% have higher biodegradability percentages compared to sample A and B, with 75.49% and 66.38% respectively.

4.3 Water Absorption Test

The water absorption test was investigated by cutting and weighing 2x2 cm squares of bioplastic film, as shown in Figure 1. Figure 2 depicts the film with different samples immersed in a container filled with 100 ml of tap water for 24 hours. The film was removed from the water after immersion, immediately dried with a cloth at room temperature, and weighed to determine the wet weight. Different samples showed different results due to the presence or absence of vinegar and eggshell. The percentage of water absorption was calculated by using the formula below:

$$\text{Water absorption (\%)} = \frac{(\text{wet weight} - \text{dry weight})}{\text{wet weight}} \times 100\%$$



Figure 1. 12x2 cm squares of bioplastic film.



Figure 2. Samples immersed in tap water.

The result in Table 4 shows that sample A has the highest water absorption, which is 35.36%, followed by sample B at 31.67%, sample D at 30.46%, and the lowest water absorption is sample C at 29.78%.

Table 4. Data of water absorption test.

Sample	Dry Weight (g)	Wet Weight (g)	Water Absorption (%)
A	0.0651	0.1007	35.36
B	0.0876	0.1282	31.67
C	0.2035	0.2898	29.78
D	0.2562	0.3684	30.46

5. DISCUSSION

5.1 Tensile

The tensile strength of the bioplastics samples is determined by the strength needed to apply to the samples to reach their fracture point. The higher the value of the strength needed to apply, the stronger the bioplastic. According to the results shown by each sample, samples C and D, which contain eggshell powder have the highest value of strength. Based on this, the addition of eggshell powder can increase the tensile strength of bioplastic.

Kasmuri & Zait (2018) suggested that the samples that contain eggshells are stronger compared to the other samples because of the membrane layer that covers every eggshell, which is separated into two types which are the outer and inner shell membranes. The membranes, which are composed of

protein fibers, are precisely parallel to the egg's surface. The link between the molecules in the bioplastic is maintained by the eggshell membrane. Thus, it can be concluded that eggshell membrane can improve the tensile strength of bioplastic.

5.2 Biodegradability

The biodegradability of the bioplastic samples is determined after 14 days in which the samples are buried in natural soil. The efficiency of the biodegradability is measured by mass loss of the samples. According to results shown by each sample, sample C and D which contain powdered eggshells have the highest mass loss percentage among all samples with 83.48% and 82.36% respectively. The higher the mass loss percentage, the faster the bioplastic could potentially completely degrade (Kasmuri & Zait, 2018). Based on this, it is apparent that the addition of eggshells is able to increase biodegradability in agar-based bioplastics.

Syed Mohamad et al. (2018) suggested that the presence of *Bacillus sp.* and *Aspergillus sp.* along with other microorganisms in the soil influenced the manner of biodegradability of bioplastics with eggshells, citing that the presence of calcium and carbon in eggshells also influence the rate of biodegradation by promoting microbial activities around the bioplastic sample. It is also important to note that biodegradability of bioplastics varies depending on the type of soil it is buried in. Kasmuri & Zait (2018) found that bioplastics degrade better in compost soil in comparison to natural soil due, but not limited, to fungus growth in the compost soil. Therefore, the addition of eggshells in bioplastics production can increase the rate of biodegradation of the bioplastics which in long term can create an eco-friendly alternative to regular petroleum-based plastics used today.

5.3 Water Absorption Test

Sample A, B, C and D show different data on water absorption test. Water absorption is the ability of a material to absorb water. Agar is recognized as a sulphated polysaccharide that possesses charged groups inside its elongated molecular chains, exhibiting characteristics of significant hydrophilicity (Hii et al., 2016). This would mean agar naturally has higher water absorption due to the positive end of the sugar molecule in agar can interact with the negative end of the water molecule. Corresponding to this, plasticizer is oftenly added in bioplastic to reduce the water absorption. Glycerol and vinegar have been used as plasticizer in this research. Vinegar is a natural preservative that contains acetic acid. With a greater concentration of acetic acid, the material tends to exhibit higher water absorption (Kadell & Callchurn, 2023). This proves the reason sample B and D having slightly higher water absorption than sample A and C. Nevertheless, the incorporation of vinegar has been observed to facilitate the regulation of fungal development in bioplastics.

Eggshells possess a notable quantity of calcium carbonate, a naturally occurring hydrophobic substance with renewable resources (Hincke et al., 2012). This characteristic contributes to the diminishment of hydrophilic entities within the bioplastic, hence resulting in a decrease in water absorption. In a separate study, the incorporation of eggshell filler into potato starch-based bioplastic resulted in a notable decrease in the water absorption capacity of the bioplastic material (Kasmuri & Zait, 2018). This phenomenon occurs due to the presence of a filler material that possesses the ability to effectively conceal the pores present inside the bioplastic (Kasmuri & Zait, 2018). Thus, bioplastics with lower water absorption tend to have higher mechanical properties such likely sample C and D.

6. DIY BIOPLASTIC KIT AWARENESS PROGRAMME

A survey has been done during Minggu Sains Negara 2023 (MSN) at Universiti Sains Islam Malaysia (USIM) to collect feedback from parents, teachers, and students from various school and universities around Negeri Sembilan as in Appendix 1. There are a total of 77 respondents collected for the feedback before and after hands-on activities bioplastic kit. The bioplastic kit provided is based on material from the best results from this research trial.

Based on the comparison between Figure 3 on the feedback before the programme and Figure 4 on the feedback after the programme, there is an increase of 40.2% in the knowledge and understanding of the respondents about bioplastics in general or agar-based bioplastics. This shows that by running this program, the respondents' knowledge about bioplastics has been successfully improved if compared to their knowledge before the programme.

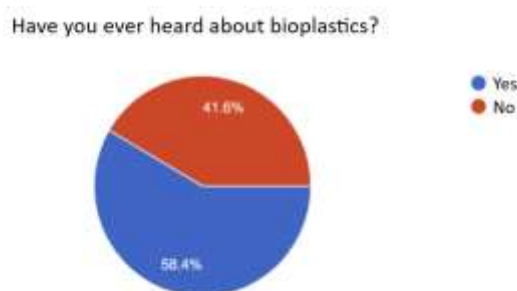


Figure 3. Respondents' knowledge about bioplastics.

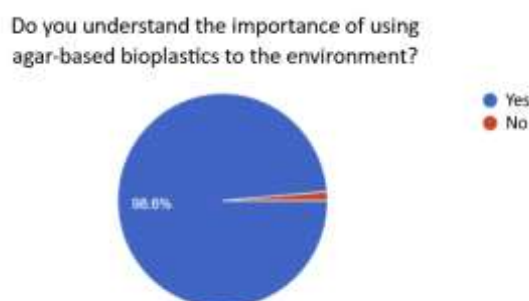


Figure 4. Respondents' understanding of the importance of bioplastics.

According to the results of the feedback from the Minggu Sains Negara (MSN), Figure 5 of the pre-feedback shows that 64 people (84.4%) respondents often use items made of plastic. However, Figure 6 of the post feedback shows that 95.9% of the respondents, a total of 71 people, are willing to replace the use of disposable plastic with agar-based bioplastic. This shows that all 64 respondents who frequently use items made of plastic, including 7 people who do not frequently use such items agree to replace the use of disposable plastic with agar-based bioplastic. This shows that after the programme was carried out, there was an increase in the number of respondents who were aware of the benefits of using agar-based bioplastics compared to disposable plastics.

Do you often use items made from plastic?

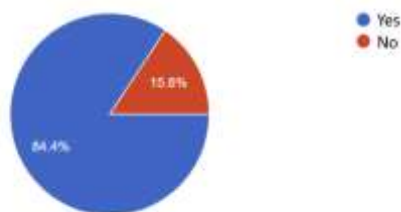


Figure 5. The frequency of using plastic.

Are you agree to replace the use of disposable plastic with agar-based bioplastic?

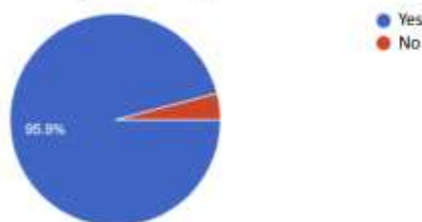


Figure 6. Respondents' views on replacing disposable plastics with agar-based bioplastics.

A comparison between Figure 7, pre-response and Figure 8, post-programme response shows that a total of 17 people (22.1%) have used bioplastics and a total of 70 people (94.6%) agree to recommend the use of agar-based bioplastics to others. There is an increase of 72.5% of respondents who are willing to use bioplastics and recommend the use of agar-based bioplastics to others. This shows that after the programme was carried out, the increase in the respondents' awareness of the benefits of using agar-based bioplastics for the environment is increasing and is highly agreed since they are ready to spread information related to this product to others.

Have you ever used items made from bioplastic?

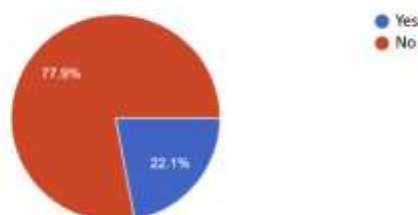


Figure 7. Respondents' experience using bioplastics.

Would you recommend the use of agar-based bioplastics to others?

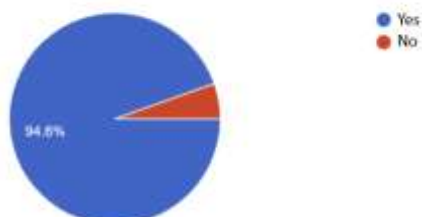


Figure 8. Respondents' views to recommend agar-based bioplastics.

7. CONCLUSION

Agar-based bioplastic is an eco-friendly plastic that contributes to more sustainable potential commercialization that follows accordingly with goals 13 (climate action), 14 (life below water) and 15 (life on land) listed in "The Sustainable Development Goals of The United Nation". The potential bioplastic produced from this research has been tested with many parameters such as the tensile test, biodegradability, and the water absorption test. Samples with vinegar are good for packaging dry foods, whereas samples with eggshell are more suited for the agricultural sector. The best result of the bioplastic has been carried out and its methodology has been introduced to the community through the "DIY Bioplastic Kit" based on the concept of a "lab in a box". Therefore, it can raise community awareness about plastic pollution, which is becoming increasingly contagious and alarming.

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APPENDIX 1

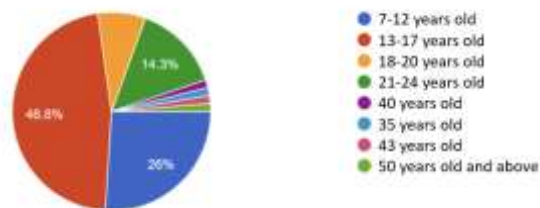


Figure 1: Respondent's Age.

Table 1: Feedback hands-on activities.

Pre-feedback	Post-feedback
Have you ever heard about bioplastics? Yes: 58.4%, No: 41.6%	Do you understand the importance of using agar-based bioplastics to the environment? Yes: 98.6%, No: 1.4%
Do you often use items made from plastic? Yes: 84.4%, No: 15.6%	Are you agree to replace the use of disposable plastic with agar-based bioplastic? Yes: 95.8%, No: 4.2%
Have you ever used items made from bioplastic? Yes: 22.1%, No: 77.9%	Would you recommend the use of agar-based bioplastics to others? Yes: 94.6%, No: 5.4%