# Environmental Impact Assessment of Active Biocomposite Packaging and Comparison with Conventional Packaging for Food Application

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**Abstract:** Reducing food wastage and minimizing pollution from food packaging are global challenges. Active biocomposite can extend the shelf life and reduce food wastage and pollution. Active biocomposite usage in food packaging is new and it's important to assess their environmental impact. This study assesses the sustainability of active biocomposite food packaging, comparing it with biopolymer and synthetic packaging using EIA framework. Results revealed that active biocomposite food packaging has the highest sustainability, followed by biopolymer and synthetic packaging.

*Keywords: Active Packaging, Biocomposite, Food, Shelf-Life, Environmental Impact Assessment*

## 1 Introduction

Around one-third of the food produced for the human being is wasted annually in the food supply chain after post-harvesting to the retail customer. More than 30 % of the food waste belongs to the fruits and vegetables (SDG Indicators, 2022). Food wastage and unconsumed food also significantly contribute to global greenhouse gas emissions. Sustainable Development Goal (DSG) 12.3 also focuses on reducing food wastage at the various phases of the supply chain (UNEP Report, 2021). The primary reason for the food wastage after harvesting is the limited shelf life and external environmental impact leading to reduced quality of food. The limited shelf life of the food is due to attacks by food-borne microbes in the food system. The conventional techniques for the shelf-life extension of packaged food are thermal processing, freezing, cooling, drying, and adding addictive chemicals (Varghese et al., 2020). Conventional methods have limitations, such as requiring energy to process and reducing the nutritional value of packaged food. Moreover, Chemical additives used in packaged food can create human health problems such as allergies, digestive problems, etc (Ben Said et al., 2019; Qian et al., 2021). So, consumer demands for chemical-free food increase with time as awareness increases (Asioli et al., 2017). Apart from that, conventional food packaging is made from petroleum-based materials such as LDPE, HDPE, and PP, which are non-biodegradable and create environmental pollution at the end of life, such as landfill problems, air pollution, and marine pollution (Srivastava et al., 2022, 2023a). Moreover, producing these packaging materials requires high energy and releasing air pollution. Made from crude oil-based materials, synthetic materials also deplete natural resources (Ncube et al., 2020).

Active food packaging with antimicrobial properties made from agri-waste fibres reinforced in biopolymers is biodegradable in nature. Active packaging creates a close microenvironment inside the package by reducing and eliminating the growth of the food-spoiling microbes (Sani et al., 2021). This results in a reduction of the growth of microbes, extending the shelf life of the packaged food. So, utilizing active packaging as a food packaging application can reduce food wastage as well as the consequences created by food wastage (Vostrejs et al., 2020). Moreover, the active packaging is made from bio-based materials such as biopolymer, natural antimicrobial agents, and natural fibres extracted from agricultural waste. So, the active biocomposite packages are biodegradable in nature and reduce environmental pollution (Srivastava et al., 2023b, 2024). Agricultural waste is a significant resource for producing biodegradable packaging materials. The utilization of agricultural waste to extract fibre for reinforcing in biocomposite also reduces biobased accumulation.

Various studies have been conducted to identify the environmental impact created by conventional food packaging (Fusi et al., 2014; Silvenius et al., 2014; Verghese et al., 2015). Various research found that synthetic packaging creates a larger environmental impact at the end of life, considering the whole life phases. Various studies have been conducted to identify the environmental impact of using biobased packaging made from biopolymers for food packaging. (Bishop et al., 2021; Garraín et al., 2007). However, its initial stage is developing active packaging made from natural fibre-reinforced biocomposite. So, it is necessary to assess the actual environmental impact created by using the active biocomposite as food packaging. In this study, the environmental impact of using active biocomposite for strawberry food packaging has been identified and compared with biopolymer and synthetic material-based food packaging. This comparison utilized the framework to assess the environmental impact in terms of a sustainability score, as designed by Singh et al., 2018.(Singh et al., 2018). This framework provides a comprehensive approach to evaluating environmental impact, considering various factors throughout the packaging's life cycle. Through an in-depth study of the environmental performance of these various packaging materials, we aim to highlight the possible advantages and disadvantages of using active biocomposite Improving environmentally friendly packaging choices in the food industry can be achieved by gaining a deeper understanding of their environmental impacts. In addition, our study adds to the continuing conversation about environmentally friendly packaging options by enabling knowledgeable choices that compromise practical needs and environmental concerns. The goal of this study is to provide significant insights to all stakeholders involved in the food packaging supply chain by thoroughly evaluating the environmental impact of active biocomposite packaging. Our research can help develop strategies that protect the environment while maintaining the quality and safety of packaged food products by identifying the environmental impacts of various types of food packaging.

## 2 Methodology

### 2.1 Packaging description

In this study, active biocomposite based packaging (a), biobased packaging (b), and synthetic packaging (c) have been chosen as strawberry packaging as shown in Fig. 1. Active biocomposite packaging (a) is made of corn starch and reinforced with rice husk fibres (Srivastava et al., 2023b). An antimicrobial agent has been encapsulated in the packaging film to impart the antimicrobial properties. Active packaging has the ability to extend the shelf life of the packaged food by creating a micro-climate inside the packaging and mitigating the growth of food-spoiling microbes (Srivastava et al., 2024). The shelf-life assessment of the strawberries has extended the shelf life to more than 11 days from 3-5 days. Biobased packaging film (b), made of polylactic acid (PLA), is conventionally used as biobased packaging in the market. However, conventionally, petroleum-based packaging (c) made of polyethylene (PE) has been considered strawberry packaging.

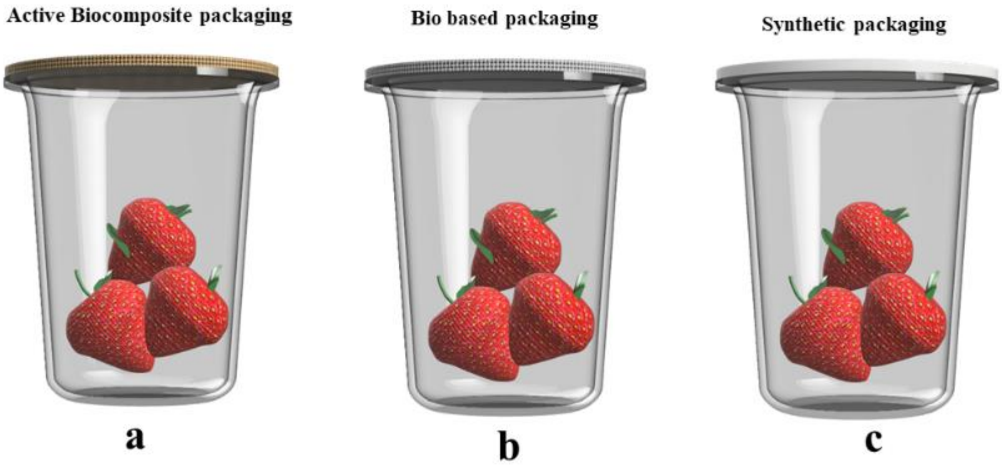


Fig. 1. Strawberries packed in (a) Active biocomposite packaging, (b) Biobased packaging, (c) Synthetic conventional packaging.

### 2.2 Environmental impact assessment (EIA)

#### 2.2.1 The goal and scope definition

EIA framework designed by Singh et al., 2018 has been implemented to assess the environmental impact of active food packaging along with biobased and synthetic packaging (Singh et al., 2018). This study was conducted in the context of the Indian market, and boundary conditions have been established accordingly. In this research, a combination of qualitative and quantitative research has been implemented. EIA of active Biocomposite based strawberry packaging and comparison with biobased and conventional synthetic packaging is designed for comprehensive analysis of the environmental consequences associated with three different scenarios of food packaging. The life cycle phases and certain boundary conditions and assumptions have been established, as shown in Fig. 2 **Error! Reference source not found.** These conditions and boundary conditions serve as the foundation for the evaluation based on each parameter. From the literature review and the boundary condition assumptions, the value of each sustainability assessment parameter has been found for all the different cases. Three different cases based on the packaging type have been listed below:

• Case a: Active biocomposite based food packaging

In this case, food packaging is made of active biocomposite materials. Biocomposite is made from reinforcing rice husk fibres and incorporates an antimicrobial agent in the starch matrix through the solution casting (Srivastava et al., 2023b). Our previous study found that the developed packaging can enhance the shelf life of packaged strawberries 11 days from

3-5 days. In the life cycle phases, sourcing raw materials such as rice husk fibres, starch, etc., and production through the solution casting method has been considered. In the next phase, the packaging of strawberries in developed packaging, followed by consumption and end-of-life phases, has been considered to evaluate the EIA.

• Case b: Biobased (biopolymer) food packaging

In this case, the food packaging is made of biobased polymer (poly lactic acid), and the manufacturing of PLA from the raw materials, production of PLA food, film, strawberries packaging, consumption, and end-of-life phases are considered to evaluate EIA.

• Case c: Synthetic food packaging

In this case, strawberries are conventionally packaged with petroleum-based materials such as LDPE HDPE film. In this case, the shelf life of packaged strawberries is limited to 3-5 days. From manufacturing to end-of-life, the whole-life phases are considered to assess the environmental impact.

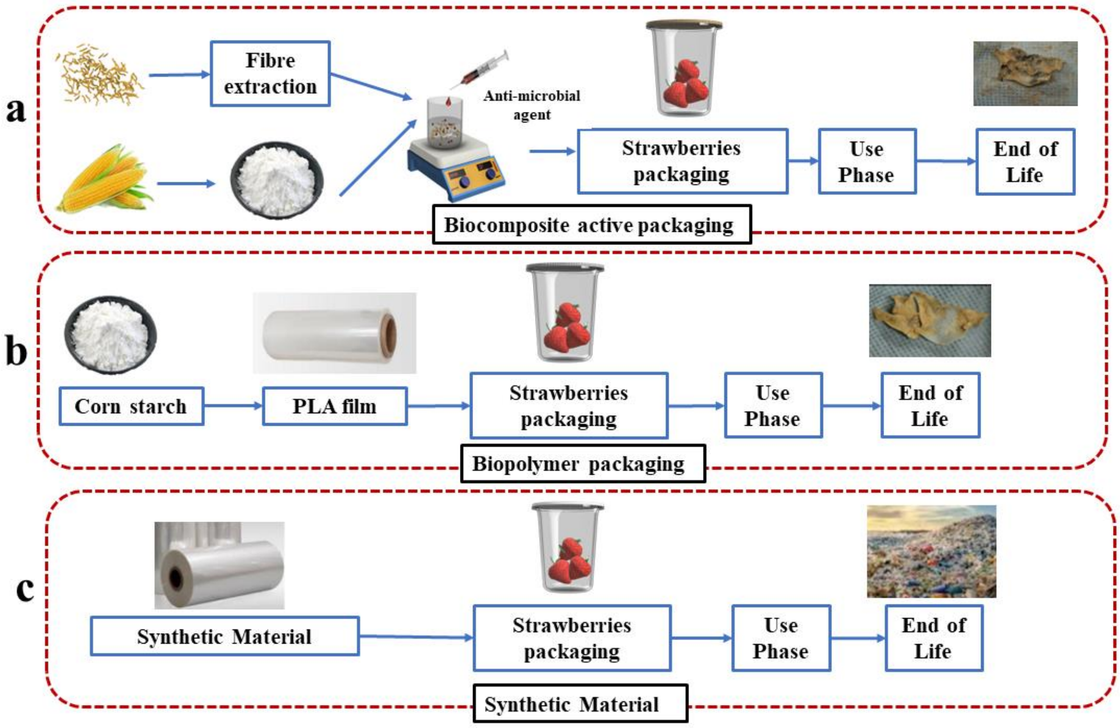


Fig. 2. Boundary condition for strawberries packaging life cycle phases for (a) made from active biocomposite, (b) made from biobased polymer, (c) made from synthetic polymer material.

2.2.2 Parameters for assessment of environmental impact

Sustainability assessment parameters were proposed in the environmental impact assessment framework designed by Sumer et al., 2018 (Singh et al., 2018). The parameters are relevant to the whole life cycle of the product/packaging, considering the environmental impact. Parameter values need to be identified through literature review and boundary condition assumptions. The parameters mentioned in Table *2* are explained, and the measurement method is as follows:

- Distance between major resources and production unit: The distance between raw material production/extraction unit and transport unit is measured in Km. So, the larger distance may require more fuel to transport the materials, creating a larger environmental impact.
- Depletion of resources in the extraction of materials: The environmental impact created by food packaging type/materials may be reduced by enhancing the use of abundant material. The use of material that is limited in nature and requires higher energy to extract, such as petroleum-based synthetic plastic, creates a larger environmental impact. It can be measured in relative terms such as Index.
- Ease of extraction: Some materials are hard to extract and require multiple processes and high energy. So, material that requires high energy to extract the materials creates a high environmental impact compared to those that require less energy in the extraction process. The ease of extraction is measured in KJ per gram.

- Material used in manufacturing: The material used in producing each package of food depends upon the design and type of material. Some materials have high density and require more materials than have lesser density. The unit of materials used in manufacturing is measured in grams per package (gram/package).
- Material wastage during manufacturing: During manufacturing, some manufacturing processes have less wastage than other manufacturing processes. So, the selection of an optimum manufacturing process and efficient supply chain leads to less wastage. The wastage during production is measured in grams per package.
- Depletion of fresh water in manufacturing: Consumption of fresh water in packaging also creates an environmental impact. If a manufacturing process requires more water than another, it means it has larger environmental impact in terms of freshwater depletion and is measured in Liter per package.
- Pollutants released during manufacturing: Pollution is released into the environment during manufacturing. Carbon footprint is a standard method to measure the pollution released during manufacturing. It is measured in $CO_2$ equivalent in Kg per package of manufacturing.
- The energy required for manufacturing: Packaging can be more sustainable by reducing the energy required during the manufacturing phase and the whole supply chain. Processes that require more energy are less sustainable. The energy required has been measured in MJ per packaging.
- Percentage of recycled material used: Utilization of recycled material instead of fresh material reduces the depletion of natural resources and energy. As much as recycled material is used, the environmental impact will be reduced, and amount of recycled materials used in food packaging manufacturing is measured in percentage (%) of the total material required.
- Distance between place of manufacture and place of usage: The distance between the food packaging unit and the consumer market also affects the overall sustainability of packaged food. If a food package needs to travel a distance to reach the consumer, it will have a higher environmental impact.
- Energy required to operate/use: Food packaging requires some energy usage while it is in transportation and refrigeration. The unit of the energy used in operation has been considered based on the relative Index. If a package requires minimum energy, the relative energy requirement will be considered for the other packaging system.
- Average life: The shelf life of a food packaging system plays an important role in deciding the sustainability of the food packaging system. Enhancing the shelf life of packaged food can significantly reduce food wastage and reduce climate change affected by food wastage. The shelf life of packaged food can be calculated in several days.
- Percentage of material recoverable: The percentage of packaging material that can be recovered after the end of the life of packaged food. The recovered material can be directly used for the same or alternative purposes.
- Energy required for recovering the materials: The energy required to make that packaging useful after the end of life is the same packaging and alternative product packaging. It can be measured in terms of energy unit KWh.
- Percentage of materials recyclable: At the end of the life of the food packaging, materials have been recycled, recovered, or reused. If the material is recyclable, it can be recycled and used as raw materials for the same purpose. If materials are more recyclable, then it will reduce the environmental impact, measured in percentage (%) of the total material used.
- Energy required for recyclability: The total energy required to convert the recyclable food packaging waste into recycled materials. If food packaging requires more energy for recycling, then it creates a larger impact on the environment. The energy required to recycle the material can be measured in KWh.

### 2.2.3 Matrix for measurement of parameters

The matrix for environmental impact measurement has been adopted from the framework for environmental impact assessment framework designed by Singh et al., 2018 (Singh et al., 2018). A metrics range was provided to assess packaging aspects based on parameter values. A five-point Likert scale is used in this approach, with 5 representing excellence and 1 representing the lowest performance, as shown in Table 1. The objective is to allocate values within this range in order to measure several packaging-related criteria, providing a thorough evaluation framework for food packaging's environmental impact.

Table 1. The metrics for measurement of environmental impact assessment.

| Parameters | Excellent | Good | Fair | Poor | Worst |
|---|---|---|---|---|---|
| | 5 | 4 | 3 | 2 | 1 |
| Distance between major resources and production unit (Km) | <500 | 500-1000 | 1001-1500 | 1501-2000 | >2000 |
| Depletion of resources in the extraction of materials (Index) | <1 | 2 | 3 | 4 | 5 |
| Ease of extraction (KJ/grams) | <500 | 500-1000 | 1001-1500 | 1501-2000 | >2000 |
| Material used in manufacturing (Grams/package) | <1 | 1.1-2 | 2.1-3 | 3.1-4 | >4 |

| | | | | | |
|---|---|---|---|---|---|
| Material wastage during manufacturing (Grams/package) | 0 | 0-0.5 | 0.51-1 | 1.1-1.5 | >1.5 |
| Depletion of fresh water in manufacturing (L/package) | <1 | 1-5.0 | 5.1-10.0 | 10.1-20.0 | >20 |
| Pollutants released during manufacturing (CO2 equivalent) | $<1\times10^{-6}$ | $(1.1\text{-}5)\times10^{-6}$ | $(5.1\text{-}10)\times10^{-6}$ | $(10.1\text{-}15)\times10^{-6}$ | $>15\times10^{-6}$ |
| Energy required for manufacturing (KWh) | $<0.5\times10^{-5}$ | $(0.5\text{-}1.5)\times10^{-5}$ | $(1.6\text{-}2.5)\times10^{-5}$ | $(2.6\text{-}3.5)\times10^{-5}$ | $>3.5\times10^{-5}$ |
| Percentage of recycled material used (%) | 75-100 | 50-75 | 25-50.1 | 05.0-25.1 | <5 |
| Distance between place of manufacture and place of usage (Km) | <50 | 50-100 | 101-150 | 151-200 | >200 |
| Energy required operate/use (Index) | <1 | 2.00 | 3 | 4 | >5 |
| Average life (Days) | >9 | 6.1-9 | 3.1-6 | 1.1-3 | <1 |
| Percentage of material recoverable (%) | 75-100 | 50-75 | 25-50.1 | 05.0-25.1 | <5 |
| Energy required for recovering the materials (KWh) | <250 | 250-500 | 501-750 | 751-1000 | >1000 |
| Percentage of materials recyclable (%) | 75.1-100 | 50.1-75 | 25.1-50 | 05.0-25.0 | <5 |
| Energy required for recyclability (KWh) | <500 | 501-1000 | 1001-1500 | 1501-2000 | >2000 |

2.2.4 Sustainability score assessment

The sustainability score of each parameter has been calculated using the method suggested by the sustainability assessment framework designed by Singh et al., 2018 (Singh et al., 2018). First, the value of each sustainability assessment parameter needs to be obtained from the literature or assumption based on the boundary condition. The relevant Likert scale value can be obtained from the matrix listed in Table 1. The individual score of each parameter for all three types of food packaging has been obtained using equation 1 as follows.

$$S_n = W_n \times M_n \qquad (1)$$

Where, $S_n$ is the score of the Individual parameter, $W_n$ is the numeric relative weightage, and $M_n$ is the value obtained on the scale of 1 to 5 from the matrix.

The total sustainability score of each food packaging ($S$) has been calculated using Equation 2.

$$S = \sum_1^n S_n \qquad (2)$$

Based on the above-mentioned formula, the overall score of the food packaging for all three cases needs to be calculated to identify the more environmentally friendly solution. The packaging system with the highest score is more environmentally friendly and creates a lower environmental impact compared to other food packaging materials.

## 3 Results and discussions

### 3.1 Measurement of values for the parameters

The sustainability assessment parameters values have been identified from the literature, and based on the boundary condition, the assumptions have been made. The values are for the producing strawberries packaging rectangular box with the size of $10\times 5\times 5$ cm$^3$. The values of the parameters for all three cases are identified based on the measurement criteria listed below.

**Distance between major resources and production unit:** The distance between major sources and production unit has been measured in Km. The synthetic plastic production unit (oil refinery) is considered in Jharkhand, about 1250 km from the synthetic film production unit. In the case of biobased and biocomposite, raw materials have been produced in Uttar Pradesh, which is 400 km from the production unit.

**Depletion of resources in the extraction of materials:** It is measured in relative Index, and it has been found that synthetic plastic is extracted from crude oil. Biobased plastic has been manufactured from crops which are renewable in nature. Biocomposite film is made from agricultural waste fibres. Biocomposite-based packaging showed the lowest Index, followed by biobased and petroleum-based food packaging.

**Ease of extraction:** Ease of extraction of packaging materials from raw materials measured in KJ/gram. The extraction of fibres from agri waste and biopolymers from renewable resources required less energy than the extraction of polymers from crude oil (Siracusa et al., 2014).

**Material used in manufacturing:** In the case of synthetic and biobased packaging, the weight of the packaging requires 2.5 grams to make the required size of packaging (10*5*5). In the case of biocomposite, active film reinforced with rice husk fibre has a higher thickness 5 grams to prepare the same size of packaging.

**Material wastage during manufacturing:** Biocomposite active packaging film is made from reinforcing of rice husk fibre. So, the extraction efficiency of rice husk fibre from rice husk is 50 % (1.25 grams of 2.5 grams) and biopolymer and synthetic material convert 100% into the packaging film.

**Depletion of fresh water in manufacturing:** Biocomposite film requires water in the cleaning process of fibres and in the solvent during manufacturing (105 ml/package), biobased packaging requires 80ml/package water during the solution casting process and mostly synthetic film are prepared by using polymer pallets (Beigmohammadi et al., 2016; Cvek et al., 2022; Srivastava et al., 2023b).

**Pollutants released during manicuring:** The pollution released has been calculated in terms of CO2 equivalent in kg per package manufacturing. So, it was found in case of synthetic packaging manufacturing showed the highest value (Bala et al., 2022).

**Energy required for manufacturing:** Total energy required to manufacture packaging in KWh /package. LCA analysis found that synthetic packaging has higher energy requirement (Bala et al., 2022).

**Percentage of recycled material used:** Synthetic material is not biodegradable, and there is a possibility of using approximately 100 % recycled material. However, in the case of biopolymer and biocomposite packaging that are biodegradable in nature, they need not be recycled (Franz & Welle, 2022).

**Distance between place of manufacture and place of usage:** The assumption has been made as per the industry availability in INDIA. So, biobased and biocomposite packaging industry is situated near the city, around 50 km, and the synthetic packaging manufacturing facility is around 200 km from the city.

**Energy required operate/use:** Food packaging operations may involve energy usage during transportation and refrigeration. The energy required can be measured through emissions during transportation and the energy used during this phase. So, the weight of the biocomposite is assumed to be two times that of the synthetic and biobased packaging. So, the energy required will be two times compared to biobased and synthetic packaging.

**Average life (Shelf-life):** The shelf life of strawberries packaged in different packaging has been measured in a number of days. In the case of active biocomposite packaging, the shelf life of strawberries has been enhanced up to 11 days. However, in the case of biobased and synthetic packaging, the average shelf life of packaged food was found to be 3-5 days (Srivastava et al., 2023b).

**Percentage of material recoverable:** Biocomposite and biobased packaging are made of natural material and are biodegradable in nature. So, reusing this material is very difficult. In the case of synthetic plastic packaging can be reused 50 % for further packaging.

**Energy required for recovering the materials:** Synthetic plastic requires chemical and mechanical action to recover the materials. However, the energy required to recover the biobased and biocomposite materials is less than that of synthetic packaging materials.

**Percentage of materials recyclable:** Synthetic food packaging can be recycled in several forms. A few biobased polymer packaging can also be recycled. However, the developed active biocomposite based packaging is biodegradable in nature.

**Energy required for recyclability:** Energy required to recycle the biocomposite food packaging and biobased, synthetic packaging has been measured in KWh. The lowest energy required to convert starch-based biocomposite packaging materials. However, recycling biobased material (PLA) requires higher activation energy than synthetic materials (Scaffaro et al., 2019).

Table 2. Measured values of parameters for food packaging for all the three cases from literature.

| Parameters | Unit | Active Biocomposite | Biopolymer | Synthetic Plastic |
|---|---|---|---|---|
| Distance between major resources and production unit | (Km) | 400 | 400 | 1250 |
| Depletion of resources in extraction of materials | (Index) | 1 | 2 | 5 |
| Ease of extraction | (KJ/grams) | 650 | 1200 | 2000 |
| Material used in manufacturing | (Grams/package) | 5 | 2.5 | 2.5 |
| Material wastage during manufacturing | (Grams/package) | 1.25 | 0 | 0 |
| Depletion of fresh water in manufacturing | (L/package) | 0.026 | 0.026 | 14 |
| Pollutants released during manufacturing | ($CO_2$ equivalent) | $1.13 \times 10^{-6}$ | $5.43 \times 10^{-6}$ | $13.2 \times 10^{-6}$ |
| Energy required for manufacturing | (KWh) | $0.23 \times 10^{-5}$ | $2.38 \times 10^{-5}$ | $5.51 \times 10^{-5}$ |
| Percentage of recycled material used | (%) | 0 | 0 | 100 |
| Distance between place of manufacture and place of usage | (Km) | 50 | 50 | 200 |
| Energy required operate/use | (Index) | 2x | 1x | 1x |
| Average life (Shelf life) | (Days) | 11 | 3 | 3 |
| Percentage of material recoverable | (%) | 60 | 50 | 50 |
| Energy required for recovering the materials | (KWh) | 259 | 259 | 800 |
| Percentage of materials recyclable | (%) | 0 | 30 | 80 |
| Energy required for recyclability | (KWh) | 600 | 1800 | 1200 |

### 3.2 Sustainability score using EIA framework

The value of each parameter has been identified and shown in Table 2 and compared with the corresponding value from the matrix of measurement on a scale of 5 to 1, as shown in Table 1. The 5 score presents the highest score, and 1 represents the lowest score. Each parameter's relative weightage has been obtained from the environmental impact assessment framework (Singh et al., 2018). The sustainability scores for each parameter have been calculated using Equation 1. It was found that parameters such as "Distance between major resources and production unit," "Depletion of resources in the extraction of materials," "Depletion of fresh water in manufacturing," "Energy required for manufacturing," and "Shelf life" are major contributors to enhancing the sustainability of active biocomposite-based food packaging. The total sustainability score (*S*) for all the three cases has been calculated based on the equation 1 and 2. In the assessment of sustainability score, it was found that active biocomposite-based food packaging has the highest score, 3.75 followed by biobased packaging 3.57, and synthetic packaging 2.97, as shown in Table 3. The outcome confirmed that food packaging made of active biocomposite materials is the most sustainable choice for food packaging, followed by biobased and synthetic packaging. For all three cases, the score and weight of each sustainability assessment parameter are listed in Table 3.

Table 3.Sustainability score of the food packaging made from Active Biocomposite, Biopolymer, and Synthetic Plastic.

| Parameters | Numeric weight | Active Biocomposite | Biopolymer | Synthetic Plastic | Active biocomposite | Biopolymer | Synthetic Plastic |
|---|---|---|---|---|---|---|---|
| Distance between major resources and production unit | 0.066 | 5 | 5 | 3 | 0.33 | 0.33 | 0.20 |
| Depletion of resources in extraction of materials | 0.068 | 5 | 4 | 1 | 0.34 | 0.27 | 0.07 |
| Ease of extraction | 0.053 | 4 | 3 | 2 | 0.21 | 0.16 | 0.11 |
| Material used in manufacturing | 0.070 | 1 | 3 | 3 | 0.07 | 0.21 | 0.21 |
| Material wastage during manufacturing | 0.064 | 2 | 5 | 5 | 0.13 | 0.32 | 0.32 |
| Depletion of fresh water in manufacturing | 0.068 | 5 | 5 | 2 | 0.34 | 0.34 | 0.14 |
| Pollutants released during manufacturing | 0.068 | 4 | 3 | 2 | 0.27 | 0.20 | 0.14 |
| Energy required for manufacturing | 0.070 | 5 | 3 | 1 | 0.35 | 0.21 | 0.07 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Percentage of recycled material used | 0.059 | 1 | 1 | 5 | 0.06 | 0.06 | 0.30 |
| Distance between place of manufacture and place of usage | 0.059 | 4 | 4 | 2 | 0.24 | 0.24 | 0.12 |
| Energy required operate/use | 0.053 | 4 | 5 | 5 | 0.21 | 0.27 | 0.27 |
| Average life | 0.059 | 5 | 3 | 3 | 0.30 | 0.18 | 0.18 |
| Percentage of material recoverable | 0.065 | 4 | 4 | 4 | 0.26 | 0.26 | 0.26 |
| Energy required for recovering the materials | 0.053 | 4 | 4 | 2 | 0.21 | 0.21 | 0.11 |
| Percentage of materials recyclable | 0.065 | 1 | 3 | 5 | 0.07 | 0.20 | 0.33 |
| Energy required for recyclability | 0.059 | 4 | 2 | 3 | 0.24 | 0.12 | 0.18 |
| Sum (Score) | | | | | **3.62** | **3.57** | **2.97** |
| Percentage (%) | | | | | 35.63 % | 34.70% | 28.86 % |

## 4 Conclusion and future work

Conventional food packaging is made of synthetic plastic and has a limited shelf life, resulting in approximately 33% of produced food being wasted annually and creating environmental pollution. The implementation of active biocomposite food packaging has extended the shelf life of packaged strawberries from 3-5 days to 11 days. Active biocomposite packaging consists of reinforcing agri-waste such as rice husk in a starch matrix, making it biodegradable. This material has the potential to reduce the use of conventional plastic packaging in food packaging, thus mitigating the environmental impact associated with synthetic packaging materials. Through the implementation of a sustainability assessment framework, it was determined that parameters such as "Distance between major resources and production unit," "Depletion of resources in extraction of materials," "Depletion of fresh water in manufacturing," "Energy required for manufacturing," and "Shelf life" significantly contribute to enhancing the sustainability of active biocomposite-based food packaging. However, parameters such as "Material used in manufacturing," "Percentage of recycled material used," and "Percentage of recyclable materials" contribute to reducing the sustainability score of active biocomposite-based food packaging. The calculation of the total sustainability score (S) for all three types of packaging highlighted active biocomposite packaging as the most sustainable option with a score of 3.62, followed by biobased packaging at 3.57 and synthetic packaging at 2.97. In the environmental impact assessment, it was found that active biocomposite-based food packaging obtained the highest sustainability score among all available packaging options. Therefore, by utilizing active biocomposite-based food packaging instead of biopolymer-based and synthetic packaging, the environmental impact can be reduced while also utilizing agricultural waste and enhancing the shelf life of packaged food.

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