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Why Biopolymer Packaging Materials are Better

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***Abstract* – The upcoming packaging material trend is bio-polymeric materials since it has shown tremendous potential in practical scenarios. Even though there have been experiments performed regarding material developments, there is still no confirmation about how uncertain the developments will be. A few statistical approaches were carried out in this work to identify the role of biopolymers as a packaging material based on their thermo-mechanical and physical properties and potential compared to other packaging materials. To determine the potential of biopolymer, it is compared with other package materials currently in demand. There are three main steps in the research. The first stage is an analysis of selected different packaging materials based on Multi-criteria decision making (MCDM) technique. The material properties are analysed through the criteria of TOPSIS analysis. The ideal and negative ideal alternatives have been identified. Biopolymers have an outcome as the final best alternative among others. To confirm the TOPSIS results and its uncertainties, a sensitivity analysis is performed. This sensitivity analysis was performed in two phases. The first step is a regression analysis of the weighted parameters and input variables of the TOPSIS scheme. The second step is the variation of weights in a unitary variation ratio to identify the order of the TOPSIS results at each variation. Finally, all the results have concluded that the research intention has been fulfilled by performing TOPSIS and the sensitivity analysis has also confirmed this decision.**

***Keywords* – Biopolymers; multi-criteria decision making; packaging materials; sensitivity analysis; TOPSIS**

Nomenclature

$A_1, A_2, ..., A_m$	Feasible alternatives out of which decision-makers have to choose
$C_1, C_2, ..., C_n$	Criteria that alternative concert are evaluated over each other
n_{ij}	Normalized value
x_{ij}	Ratings of the alternative “A” to criteria “C”
w_j	Relative weight of the j^{th} criteria or attribute
v_{ij}	Weighted normalized value
Ω_b, Ω_c	Sets of benefit attributes and cost attributes, respectively
S_i^+	Separation of each alternative from the ideal solution
S_i^-	Separation from the negative-ideal solution
C_i^+	Relative closeness to ideal solution

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1. INTRODUCTION

Packaging is an application in most food and pharmaceutical industries designed to contain the goods and protect them during manufacture, distribution, and storage at a minimum cost until the goods reach the customer [1]. After they reach the consumer usage stage, the main role of the packaging is fulfilled. Other industries also use packaging materials at least at one stage of their production process. The main function of packaging is to protect all types of materials with its design and keep the product apart from the outside environment at a considerable level [2]. It is an absolutely necessary aspect for each product to add to its value [3]. Packaging also prevents both chemical and physical damage to the product. Also, the containment ability of packaging determines the size of each product. Barrier properties from moisture, chemical, microorganism, and oxygen are also important for packaging materials to retain the product's quality [2], [4]. The convenience of these properties helps consumers with their day to day applications such as reuse, microwaving, resealing, etc. Soft drinks, fruit drinks, beer, and other liquid products require pre-dispensing before use, thus the packaging facilitates this and the processing requirement, such as with canned foods.

Hence, the research intention is to perform an analysis of different packing materials in terms of comparative package materials, their nature, and inherent properties, all of which are to be analyzed in this work.

The selected package materials are glass, paper, textile, plastic, composite material, and biopolymers. The material selection is based on current demand, technological effectiveness, and potential for reducing future problems [5]. Since there are a lot of varieties in the above materials in the market, basic chemical structures have used for analysis for this analysis. In past research, scientists have used these basic chemical structures to enhance material properties [5]–[7]. To calculate the uncertainties of output properties these basic structure material properties can be used. Further information regarding the selected materials is provided in the sections below.

1.1. Glass

Glass is widely used as a packaging material in every industry. The main reason glass is a suitable material for packaging is not only due to the chemical inactivity of silica but also due to its long term reusability, barrier properties, transparency, strength, and ability to mold easily. Nonetheless, the breakability quality of glass packaging under shocks, heaviness and its vulnerability under temperature shocks are the negative aspects of using glass for packaging [8], [9]. The production of glass includes high temperature (around 1500 °C) conditions. Glass mixture melting, pre-molding, final molding using compressed air and cooling are the basic stages in the production of glass before it becomes a consumer product. Breakability under shocks means the use of glass as a primary packaging material is limited in industries. In this research, soda-lime glass [8]is used for the evaluation.

1.2. Paper

Paper is very popular among most industries as a cheap, widely higher abundance and flexible packaging material. Paper can be used in both flexible and rigid applications. Production of the paper consists of a few steps. First, moistened cellulose fiber pulp is derived and secondly dried into flexible sheets [10]–[11]. Examples of these flexible sheets are bags, wraps, waxed paper, glassine, kraft paper, and greaseproof papers and liners. Kraft papers are used as the comparative material for this research. Dried meat scraps and grains, granulated sugar and powdered milk are packed with kraft paper sacks. Also, kraft paper is used for making the outer secondary packaging of paperboard and cardboard cartons. The manufacturing of frozen food packs and liquid packaging containers use PE-kraft paper. Polyester-coated kraft paper containers and trays have a higher resistance to the temperature which means that these materials can be applicable for electric ovens and microwave ovens. The main reason for the remarkable popularity of paper packaging is its eco-friendliness [11], [12], price, long-term reusability, and biodegradability. However, when it comes to surface properties such as moisture and liquid absorptivity, the paper is not the preferred packaging material.

1.3. Textiles and Composites

Potatoes, tea leaves, coffee, sugar, and dried cereals are used in textile package synthesis. However, plastics and composite material bags are fast to overtake the use of cloth bags within the past few decades since its enhanced barrier and strengthened property containing packaging material is composite [13]. Typically, packaging containing composite materials are used by the beverage and dairy industries for soft drinks, fruit juices, and dairy products. Glass, paper and textile materials have been used as packaging materials in different ways due to their abundance. Composites have been applied to all the materials to enhance their properties and to reduce their negative points. The development of technology [12], [13], population growth and urbanization has led packaging technologies into an alternative – plastics.

1.4. Plastics

Plastics for packaging can be categorized as commodity plastics or barrier plastics. Polyethylene(PE), polypropylene (PP), polystyrene(PS), and polyvinyl chloride (PVC) are examples of commodity plastics [10], [14]–[17]. Compared to barrier plastics, commodity plastics are cheaper with poor oxygen barrier property. Polyvinylidene chloride and ethylene-vinyl alcohol copolymer are barrier plastics, which are high in price but perform excellently in terms of oxygen barriers when compared to commodity plastics. PE is the most popular packaging material among industries. Plastics can be produced in most of the density conditions, and the most common example is low-density polyethylene (LDPE) [17] and high-density polyethylene (HDPE) based on density difference [18]. Lots of plastic applications are nowadays abundance in different material property conditions.

Although plastics are a good packaging material for industries in terms of consumer friendliness and cost-effectiveness, they have a negative impact in terms of environmental sustainability as they result in unrecoverable damage due to their low degradation rate under normal environmental parameters. In addition, under oxidation reactions and burning conditions, plastics emit a higher number of greenhouse gases (GHG) and gases which are toxic to humans and living things [14]. A considerable amount of research has been carried out on bio-packaging with an intention to overcome these problematic issues with plastics.

Plastics manufacturing uses a huge amount of fossil fuels, energy and chemical components and also heat is released to the environment as a sub-product during the process [19]. Resource depletion and harmful waste releases have caused unrecoverable damages to the environment due to this product manufacturing. Therefore, recent researchers have focused on environmentally friendly natural materials as their next packaging material step in industrial applications. For this analysis, HDPE [18] has been considered in terms of being representative for the 'plastics' material type.

1.5. Agro Fiber-Based Plastics

To overcome the non-degradability problem of plastics currently, material scientists are carrying out research with the intention of inventing biodegradable plastics. Already they have achieved some properties such as matrix breakdown from sunlight exposure. The starch plastic combination is the recent achievement regarding matrix breakdown from sunlight. Even so, it has still not reached the 100 % breakdown under the sunlight [20].

1.6. Bacteria-Based Plastics

Another type of bio-plastic material is bacteria-based plastics. PHA polymer chains which are synthesized inside bacteria cells are used to make the films. Mechanical properties can be changed depending on the intention. The type of bacteria and growth condition can influence the polymer outcome. PHA enhances the biodegradability, thermal resistance property and mechanical flexibility of a packaging material [21].

The very recent invention is genetically modernized bacteria which has an ability to produce biodegradable plastics via cell metabolic reactions. Yet it is not very cost-effective for the industries. Nowadays, a polyester material named as Ecoflex also applied to food packages. But the issue of CO_2 releasing to the atmosphere made it as a failure. By looking at the recent developments, the main focus (requirement of sunlight to degrade) of biodegradable plastics need to be diverted in another way. Because it will not help the already buried landfill waste [14], [21]. Therefore, it will last in the environment for a long time period. By affiliating the above techniques synthetic polymer and biopolymer mixture (agricultural raw waste) are proposed for the packaging due to their inexpensiveness, wide availability and user-friendliness but the expected material strength properties did not achieve.

1.7. Lignin-Based Plastics

Lignin-based plastic is another low cost renewable biodegradable plastic option and it enhances the compatibility of the matrix polymer and UV stability [22]–[24]. Positive compatibility with both natural and synthetic polymers will occur because of the interaction in between diverse functional groups of matrix and lignin. Lignin has resulted in high modulus value from the reinforcing action and thermal stability. Thermal insulation values also are a bit higher than the other materials.

1.8. Soy-Based Plastics

Soy-based plastic is another alternative for biodegradable plastics. Hence it has a limited number of proteins with fats and oils which allow soy to become molded into films and plastic material. Commonly it has been used in food coatings and vehicle applications. Due to its low availability, this material is not applicable [25].

1.9. Natural Fiber Reinforced Plastics

Nowadays, natural fiber reinforced plastics are used due to their low cost, high modulus value, abundance, low density, the high number of reactive ends on the surface, ease of the process and high biodegradability. As reinforcing agents, bamboo, flax, hemp, pineapple, and kenaf are added for the polymer matrix. But it shows a brittle property for the tensile test. PLA and natural kenaf fiber complex have increased modulus value with heat resistivity. Also, high flame retardance is enhanced by adding phenol novolac and aluminum hydroxide in PLA. Carbon dioxide absorption ability of natural fibers also has an extra advantage [1], [20], [21].

Due to non-renewable raw material usage and accumulation of non-biodegradable materials, it has become an environmental problem. As a result of that, biopolymer packaging comes into play [23], [26].

1.10. Biopolymer

Biopolymers have resulted in biodegradable packaging by reducing the shelf life of plastics and also enhanced plastic recycling programs. Polysaccharides, proteins, lipids, and polyesters are the four types of biopolymers that are widely used in packaging. Polysaccharide and protein composed films show better mechanical and optical properties. On the contrary, lipid-based and polyester-based packaging films showed fine water vapor barrier properties [9], [27], [28]. The reasons are described below.

1.11. Polysaccharide-Based Packaging Materials

For the packaging purpose cellulose, starch, chitosan, alginate, and pectin like polysaccharides are commonly used. These polysaccharides have the capability to synthesize films with better gas and vapor barrier properties. Also, considerable tensile strength and percentage of elongation have been achieved too. The tensile strength values of each polysaccharide-based packing material types are different from each other, but some are close to the observed synthetic polymers values [29].

Initially, in film synthesizing process of polysaccharides, the raw materials are dispersed in a polar solvent or a mixture of polar solvents [30]–[34]. Lately, after adding antimicrobial agents, plasticizers and coloring additive agents to the mixture pH and heat conditions are adjusted. Film casting is done in either dipping or dispersing method by drying. The polysaccharide-based materials have a cost-effective and functional property nature [35], [36]. Therefore, these packaging methods are highly available among the industries.

High-density polyethylene and polysaccharides are sometimes at a competitive level when it comes to some properties, such as tensile strength and percentage of elongation of thin films that are made out of unmodified chitosan and amylose, which are quite comparably equal in values. Currently, ongoing polysaccharides based research projects have mainly focused on the improved barrier and mechanical developments. Chitosan is the lead among them so far. The final intention is to produce a biopolymer that can be replaced by all the existing synthetic polymeric materials on the market [37], [38].

1.12. Protein-Based Packaging Material

The base unit of the proteins is amino acids. 20 amino acid unit get together to form a protein. Due to the variety of amino acid composition of a protein makes a higher number of different polymer chains and also, a large variety of chemical and physical property changes. Polysaccharides have limited types of monomers only. But for proteins, there is a large number of monomers due to different types of functional units in monomers [39]–[41]. Therefore, when we use protein as a packaging material it will result in a variety of properties which are very important for the packaging purpose. Protein packaging films have prominent barrier properties, transparency and gloss of final product under general environmental conditions and humidity conditions than in polysaccharides and lipid films due to the vast number of monomers in structure [42]. Development of protein matrix has overcome the low mechanical properties of protein package films by enhancing the tensile strength.

1.13. Lipid-Based Packaging Materials

Lipids are naturally abundant biopolymer macromolecules, which have a small number of repeating units to make a large network structure. Therefore, their properties are comparatively different from polysaccharides and proteins. Lipid structure is a low polar. Usually, lipid polymeric packaging materials are used as protective layers only. Usually, lipid films are not self-supportive and they are most fragile. Lipid has high moisture barrier properties due to wax layers that have been used as edible packing materials [42]–[44]. Even though the growth of microbes and greasy texture gives a negative drawback for lipid while using it as a packaging material. But lipids together with other biopolymer types shows higher performance than when they are alone. This is a point that should be concerned.

Biopolymers were mainly developed with the main intention of environment-friendliness but also, its competitive properties (temperature resistance, thermal conductance, oxygen transmission rate tensile strength and water vapor transmission rate) compared to other materials as a thermal packaging are excellent. Meanwhile, the bulk material abundance, renewability, and recyclability are providing better colors to biopolymers [4], [16]. For this research work analysis industrial cellulose bag package materials have been used since they have a very low modified structure composition as concerned in the analysis. The reason for this is that cellulose is the most abundant biopolymer material among the others and most of the research has concerned cellulose as an icon in their developments.

2. METHODOLOGY

All the extracted responsible literature values for alternatives found and criteria and alternatives were defined.

By following the principal steps of TOPSIS, calculations were performed as in the below description [45]. The mathematical expression and conclusion were gathered by using computer technology. Also, for this research, work sensitivity analysis has been carried out under two different pathways [46]. The reason for using two different types of methods for identifying uncertainty is due to that initial calculations of first stage sensitivity analysis mainly considered on the relationship between the input variable and outcome of TOPSIS results. After that, another stage of calculations has been processed to identify the uncertainties in the weighted parameters of TOPSIS calculations.

2.1. Material Selection

Glass, paper, plastics, textiles, composites, and biopolymers were selected as comparative alternatives. Temperature resistance (ºC), thermal conductance (W/(m·K)), oxygen transmission rate – OTR (23 ºC/cc/m^2/24 hr), water vapor transmission rate (g/m^2·day) and tensile strength (MPa) values for above materials were sorted out for further TOPSIS calculations as criteria. Industrial competitive abundance, potentials for reducing unforeseen problems and literature value available for each criterion are the main reasons which have been considered to choose material types [28], [45], [47], [48].

2.2. TOPSIS (Technique for Order Preference by Similarity to the Ideal Solution) Analysis

Multi-criteria decision making (MCDM) methodology has been widely used among most industries and decision making parties to solve problems and to attain an optimal decision [47]. This MCDM technique has robust advantages in failure sorting operations.

Nowadays, the below-mentioned techniques are used widely problem-solving MCDMs among decision-makers:

- SAW (Simple Additive Weighting);
- TOPSIS (Technique for Order Preference by Similarity to the Ideal Solution);
- ELECTRE (Elimination and Choice Translating Reality);
- AHP (Analytical Hierarchy Process);
- SMART (Simple Multi-Attribute Rating Technique);
- ANP (Analytic network process).

The Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) method is a classical successive method among the other MCDM techniques [46], [49]. The final resultant alternative of TOPSIS describes the closest to the ideal solution and furthest from the negative ideal solution. The intent of this paper is to discover a packaging material from a set of alternatives based on their thermal, physical and mechanical properties by using TOPSIS analysis. It sequentially reduces the number of alternatives from a set of possibilities. TOPSIS has been proven as an optimized procedure when finding the best from a set with similar characteristics.

Normalization is the specialty of this technique. It helps to linear the value by using linear normalization vector normalization. In the first period of TOPSIS usage, decision-makers were only using vector normalization. By the time past, a new development of data linearization was adopted by decision-makers.

In this method two artificial alternatives are hypothesized:

- Ideal alternative – the best attributes valued one (high benefit attributes and low-cost attributes);
- Negative ideal alternative – the worst attribute valued one (minimum benefit attributes and maximum cost attributes).

The TOPSIS method selects the alternative that is the closest to the ideal solution and furthest from the negative ideal solution. The basic concept of this technique is to separate the best alternative from a set of alternatives compared to similar characteristic properties. The chosen best alternative is the closest to the ideal solution and furthest to the negative ideal solution [45].

To see packaging material scenario in a new dimension it is important to determine which material shows optimal condition with its low modified structure condition (without doing any complex chemical modification) and multi-criteria analysis technique provides a fascinating opportunity for the clarification of this issue.

For this research, TOPSIS analysis weights were defined on a rating scale of 10–0 as per the performance value of those criteria in the package material property aspect. Such as excellent performance – 10, better – 9, very good – 8, good – 7, average – 6, close to average – 5, poor – 4, very poor – 3, very-very poor – 2, not enough to compare – 1, reject – 0. TOPSIS calculations were carried out according to these weights [45], [50].

The basic concept of this technique is to separate the best alternative from a set of alternatives compared to similar characteristic properties. The chosen best alternative is the closest to the ideal solution and furthest from the negative ideal solution.

The TOPSIS method has a few steps:

1. Step 1: Construction of decision matrix with rankings by expressing it in a matrix format as:

$$D = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{vmatrix} C_1 & C_2 & \cdots & C_n \\ x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & x_{m3} & x_{mn} \end{vmatrix}, \tag{1}$$

where A_1, A_2, ..., A_m is possible alternatives and C_1, C_2, ..., C_n is criteria that alternative agreement is evaluated between each other. Ratings of the alternative "A" to criteria "C" are noted as x_{ij}.

2. Step 2: Determination of normalized decision matrix.

This step will transform dimensional attributes into non-dimensional attributes by opening the pathway for different criteria comparison. This can be calculated by using Eq. (2):

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^{2}}}. \tag{2}$$

3. Step 3: Determination of the weighted decision matrix:

$$v_{ij} = w_j \cdot n_{ij}, \tag{3}$$

where w_j is the relative weight of the j^{th} criteria or attribute.

4. Step 4: Determination of ideal and negative ideal solutions:

$$A^{+} = \{v_1^{+}, v_2^{+}, \ldots, V_m^{+}\} = \{(\max v_1 \mid j \in \Omega_b) \cdot (\min v_1 \mid j \in \Omega_c)\}, \tag{4}$$

$$A^{-} = \{v_1^{-}, v_2^{-}, \ldots, V_m^{-}\} = \{(\max v_1 \mid j \in \Omega_b) \cdot (\min v_1 \mid j \in \Omega_c)\}, \tag{5}$$

where Ω_b and Ω_c are sets of benefit attributes and cost attributes.

5. Step 5: Separation measurement calculation.

Separation can be calculated by using the below n-dimensional Euclidean distance equations Ideal separation:

$$S_i^{+} = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_{ij}^{+})^2}. \tag{6}$$

Negative ideal separation:

$$S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_{ij}^-)^2}\ , \tag{7}$$

where i = 1, 2, 3, ..., m.

6. Step 6: Determination of relative closeness.

The relative closeness of alternatives with respect to the ideal solution can be calculated by using this equation:

$$C_i^+ = \frac{S_i^+}{S_i^+ + S_i^-}\ , \tag{8}$$

where i = 1, 2, 3, ..., m.

7. Step 7: Rank according to the preference order.

The greater value of relative closeness designates high performing alternative of the set. The calculation results were illustrated in the discussion step. The obtained results were used to calculate the sensitivity of the outputs for a distraction in weights [50].

2.3. Sensitivity Analysis

Sensitivity analysis is a technique which works on the behavioral change of a model [46]. The percentage of uncertainty is calculated through this. On the one hand, one input is kept constant, on the other – the next input is varied while keeping others in a constant mode. There are three parameters that we need to be considered while doing the sensitivity analysis:

1. Experimental design;
2. Variable;
3. Expected observation.

These factors are the key factors while doing a sensitivity analysis. The intentions of this filtering factors can be used to identify the experiment path of the analysis as in Fig. 1. The sensitivity analysis is the main approach that provides a test of the uncertainty of data and results [46].

This uncertainty foundation has provided a platform to find it in a statistical way. Mainly these techniques are based on mathematical algorithm. Sensitivity analysis is computationally based. Mainly there are two types of sensitivity analysis techniques that are a presence in the field:

– Modeling and simulation techniques;
– Scenario management tools of *Excel*.

In order to proceed with these techniques, there are two main approaches for the foundation and these techniques are an adaptation of TOPSIS initial stages:

– Local sensitivity analysis;
– Global sensitivity analysis.

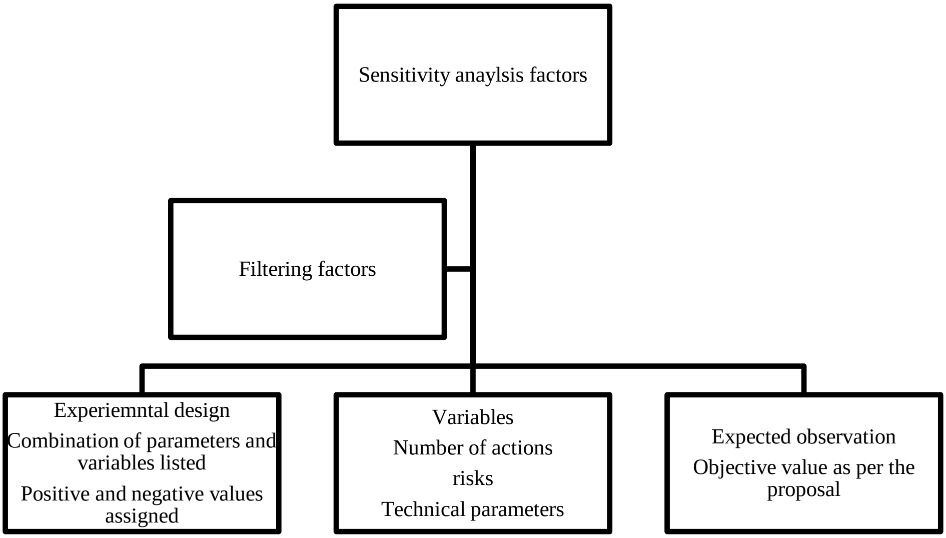


Fig. 1. Sensitivity analysis factors.

The local and global analysis is mainly differentiated from others in terms of their application. Local sensitivity analysis is an analysis that is used to calculate the impact of input factors. The evaluation is carried out using partial derivatives or gradient of the final output function. for the mathematical derivatives will be given as the answer. In the global sensitivity approach, Monte Carlo theorem has been used. No mathematical expressions are included. There are different types of sensitivity techniques that have been widely applied in the fields.

TABLE 1. SENSITIVITY ANALYSIS METHODS

Method	Description
Correlation analysis	This analysis finds the relationship between independent and dependent variables. This will show the strong bond of the used two parameters with each other. In order to calculate the correlation, the coefficient dependency of the two variable has to be calculated. Mostly computational software has been used for these calculations
Regression analysis	This analysis finds responses to complex modeling methods. The linearity of input and output will be the result
Subjective sensitivity analysis	This method is subjective for input parameters and individual analysis is carried out for further clarification
Differential sensitivity analysis	Simple partial derivatives have been used for making the relative comparison between different variable inputs
One time at a time sensitivity analysis	The most fundamental partial derivatives are used to make a comparison between each input variables
Factorial analysis	A factorial number is obtained as a result of input variable comparison

Finding the uncertainties of a given output data set are the main function of sensitivity analysis. This technique has an ability to predict the forecasted information about the output variables if the situation turns out different or changed. Also, this can be used as a decision-making technique since it results in the percentage of uncertainty and expressing the changes in a model behavior [49], [51], [52]. The risk assessment is another benefit of the sensitivity analysis. This will help to take appropriate decisions with a clear mind without having any errors in the model. Also, sensitivity analysis is a method for upgrading the obtained results of TOPSIS with better certainty of the decision made [45], [50].

In the first stage, *Microsoft Excel – what-if* analysis tool was used to obtain the regression model for each TOPSIS output and secondarily unitary variation ratio of weights was performed. By considering five criteria as the distracting parameters for the assessment unitary variation ratio has been used in a value range of 0.01, 0.02, 0.03, 0.05, 0.1, 0.2, 0.5, 1, 1.5, 2, 2.5, 3, 3.5 and 4.0. The weighted parameters were distracted one by one into this ratio so that relative closeness values can be recalculated [46]. According to those results, the order has been recalculated. This procedure was performed for all five parameters.

The performed TOPSIS weighted parameters have been used for this stage of calculations. If we assume that the used weights are distracted in k = 1, 2, 3, ... proportion to results w_1, w_2, w_3, …, w_k and w_n for each parameter. The distracted weighted parameter can be calculated by using the below formulas [46].

$$w_k' = \frac{w_k *}{w_1 + w_2 + \ldots + w_k * + \ldots + w_n} = \frac{w_1}{1 + (\gamma_k - 1) w_k} , \tag{9}$$

where w_1^1 is the value after the first distraction to the weighted parameter. According to the k^{th} parameter distraction w_k^1 can be obtained as in below:

$$w_k' = \frac{w_k *}{w_1 + w_2 + \ldots + w_k * + \ldots + w_n} = \frac{\gamma_k w_k}{1 + (\gamma_k - 1) w_k} , \tag{10}$$

where $w_k^* = w_k \cdot \gamma_k$.

The B_k can be obtained by using the above formulas in order to identify the unitary variation ratio of the w_k disturbance:

$$B_k = \frac{w_{k1}}{w_k} . \tag{11}$$

By substituting the B_k value to the below equation γ_k can be calculated for the calculation of unitary variation ratio [46]:

$$\gamma_k = \frac{B_k - B_k w_k}{1 - B_k w_k} . \tag{12}$$

By considering five criteria as the distracting parameters for the assessment unitary variation ratio has been used in a value range of 0.01, 0.02, 0.03, 0.05, 0.1, 0.2, 0.5, 1, 1.5, 2, 2.5, 3, 3.5 and 4.0. By varying the weighted parameters one by one into this ratio, the relative closeness values can be recalculated. According to those results, the order has been recalculated. This procedure was performed for all five parameters. The results for the calculations are illustrated in the discussion section [46].

The weighted parameters are distracted six times as below:

– Each weighted parameter has changed one by one by keeping other parameters in settle mode;
– All the parameters are changed together one time.

The intention of changing the parameters all together is to see if the distracted values remain unchanged or not. Lately, the order was rearranged to check whether the order has changed or not. By using the previous literature theoretical analysis [46] this unchanged can be further clarified. Results of the calculations are illustrated in the discussion section.

3. RESULTS AND DISCUSSION

The necessary values are extracted through the literature sources and units are considered as standard units in order to maintain a justifiable comparison between each packaging material. Table 1 contains the temperature resistance in Celsius degrees (0 °C), thermal conductance in Watts per meter Kelvin (W/(m·K)), oxygen transmission rate (OTR) in cc/m^2/24 hr at 23 °C, water vapor transmission rate in gram per cubic meter within a day (g/m^2·day) and tensile strength in mega Pascal (MPa). The TOPSIS analysis is carried out by using the below data in Table 2.

TABLE 2. TOPSIS ANALYSIS DATA SET

	Temperature resistance, °C	Thermal conductance, W/(m·K)	OTR at 23 °C, cc/m^2/24 hr	Water vapor transmission rate, g/(m^2·day)	Tensile strength, MPa	References
Glass	1000	0.96	0.0003	7	33	[30], [54], [8], [29], [28]
Paper	132	0.0904	800	15	22	[1], [38], [4], [55]
Plastics	300	0.2	2000	120	37	[1], [4], [14], [16], [17], [20]
Textiles	154	0.774	300	180	75	[56], [57], [58]
Composites	300	0.25	11	125	250	[17], [2], [1]
Biopolymers	220	0.12	4.9	142.76	150	[7], [33], [47], [2], [28], [54]

According to the values, glass has higher thermal resistance and the silica nature of glass provides evidence to that [8], [53]. Also, the OTR and water vapor transmission rate values are low in glass because of the compact nature in the matrix. Nonetheless, low tensile strength and poor shock resistance have reduced the power of the above properties. Even though plastic has low conductivity, it cannot be considered as a good thermal packaging material by itself when compare with biopolymers and composites competitive properties. According to the industrial rule of thumb for a better O_2 barrier material, OTR should be less than 15.22 cc/m^2/24 hr at 23 °C, but plastics have a quite high OTR than other packaging materials.

All the sorted results are compared with each other according to the TOPSIS methodology and a ranking of relative closeness has been made. The normalization matrix [45], weighted normalization matrix, the ideal and negative ideal solution, separation and relative closeness ranking have calculated. All the sorted values are converted into non-dimensional scale by using normalized decision matrix. The relative weight of the j^{th} criterion or attribute w_{ij} is calculated to construct the weighted decision matrix. The alternative that is closest to the ideal solution and furthest from the negative ideal solution can be calculated by using separations of the ideal and negative ideal solution. Lastly, the ranking of different packaging material types based on thermal, physical and mechanical properties have been obtained accordingly.

C_i or the relative closeness should always be in the $0 \leq C_i \leq 1$ range; C_i =1 if has only best solution conditions. Also, in parallel C_i = 0 if the alternative has the worst conditions [51].

In Fig. 2 relative closeness results of the six materials have been illustrated in a graphical way. TOPSIS results showed that relative closeness to the ideal solution of a biopolymer is higher than the other packaging materials. Relative closeness signifies the closest of alternatives to the ideal solution and how furthermost to the negative ideal solution. According to the ranking, biopolymer has reached no 1 among the other materials while having a competition with composites.

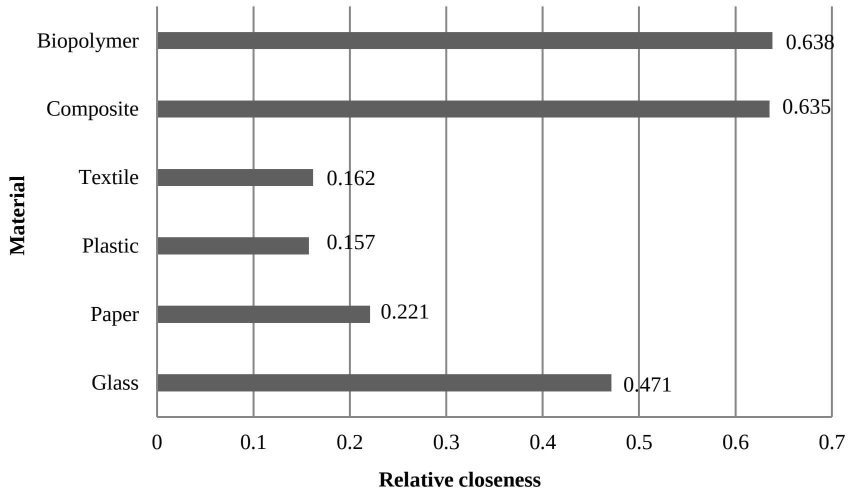


Fig. 2. MCDA TOPSIS analysis results of different packaging materials.

The reason for biopolymers rank is its overall performance in each property. Even though glass, paper, and plastics show extremely high rates in some properties, at the same time show extremely low ratings for other properties [45], [46], [51]. Biopolymers and composites do not have extreme properties but they always show the necessary levels which are required for thermal packaging. Therefore, biopolymer materials are better in thermal packaging when compared to the other materials. It will not only be a better packaging material but also an environmentally friendly solution in the near future.

As per the regression sensitivity analysis results, biopolymer has become number one among the other materials due to its low uncertainty property with the changes of the model. Here below is the final conclusion of the regression sensitivity analysis [49], [46].

TABLE 3. REGRESSION MODEL
RESULTS OF DIFFERENT PACKAGE MATERIALS

Material	Regression results
Glass	0.9408
Paper	0.8869
Plastics	0.887
Textiles	0.9095
Composites	0.9678
Biopolymers	0.9715

Looking at the results, competition between composites and biopolymer is still remaining. Composite is a material which has hydride properties of all normal materials. Therefore, selective composite material might have inherent biopolymer properties. But still, they did not reach the level of biopolymers levels. Therefore further analysis has been carried out to check whether the order has changed or not [49].

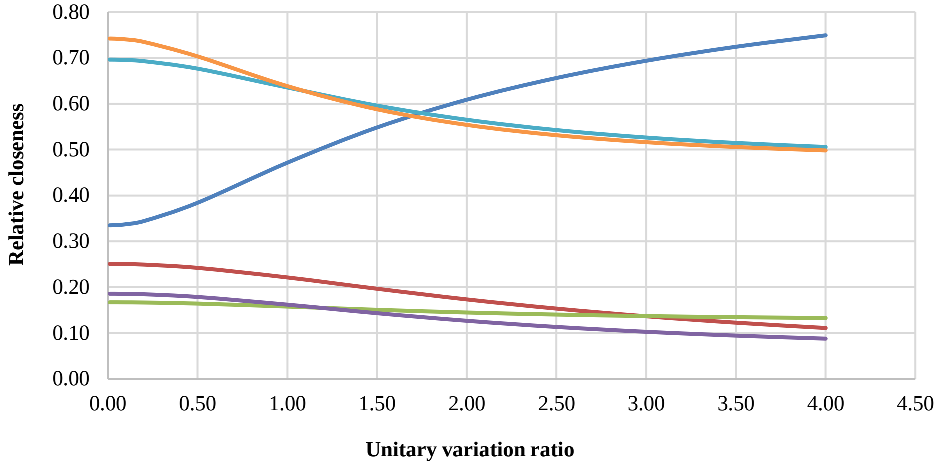
According to the below Fig. 3, it shows that the distraction of parameter w_1 has resulted in disturbances in the 0.5 to 0.75 and 1.75 to 1.90 range. These weights were sensitive until 0.5 and again insensitive to the distraction. At 4.0 unitary ratio again it is sensitive. The relative closeness order (Biopolymer > Composite > Glass > Plastic > Paper > Textile) has changed after unitary ratio has reached to 1.0, also the order has changed to glass > biopolymer > composites > plastic > paper > textile. The reason is that glass has a high thermal resistance property [46]. Varying the weighted parameter values of glass has resulted in a positive relative closeness to the ideal solution. Therefore, the sensitivity of glass is low compared to the other materials.

Compared to the w1 graph, w_2 (Thermal conductance) and w_3 (OTR) are relatively high in sensitivity. The reason is biopolymer has low sensitivity meanwhile its relative closeness gets high by close to the ideal solution [46]. But composite has less sensitivity than biopolymers. Also paper, glass, and textile together show little less uniformly throughout all the distractions. But their relative closeness value is decreasing.

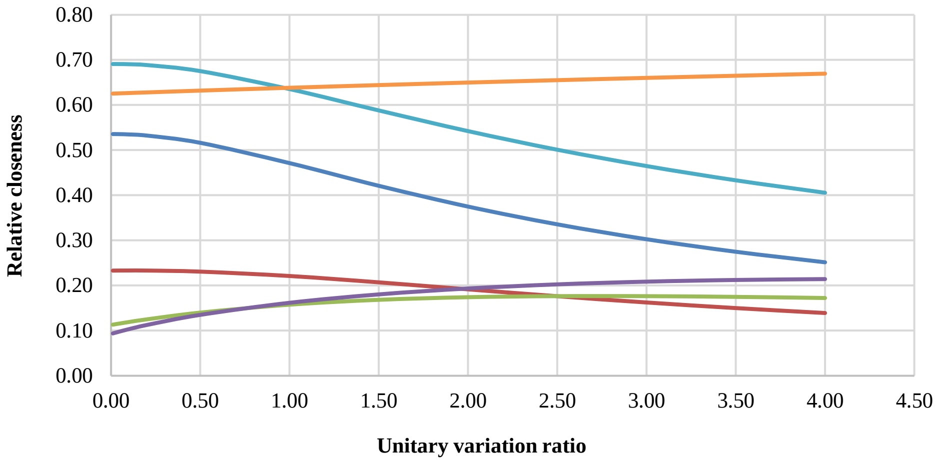
In w_4 parameter condition sensitivity of biopolymer is much lower than compared to the other materials. Also, the relative closeness order change is not that significant because the values are distracted really slowly by the unitary ratio. Therefore, in parameter w_2 and w_3 both scenario order is leading by biopolymers with sensitivity.

Fig. 3 above illustrates the relative closeness values with different unitary variation ratios with respect to the parameter w_4 (WVTR) weight change. In the range of 0.7–0.8, all the materials are performing a change in their variability pattern [46]. Also at the 4.0 range, all the materials reach a steady state with sensitivity also meaning while paper material is climbing up with achieving a relatively high relative closeness value compared to its previous stages. Also, the composites and glasses are showing a similar variability when compared with biopolymers. But still, plastics are showing poor properties while showing low relative closeness with high variations with distractions.

Parameter w_5 or Tensile strength property weights have been distracted by using unitary ratio values. The values are showing that biopolymer and composites compete in terms of reaching a maximum relative closeness value. At the value 4.0, every material reaches a uniform variation along x-axis by showing high sensitivity.


Relative closeness
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.00 0.50 1.00 1.50 2.00 2.50 3.00 3.50 4.00 4.50
Unitary variation ratio

(a)


Relative closeness
0.00
0.10
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0.30
0.40
0.50
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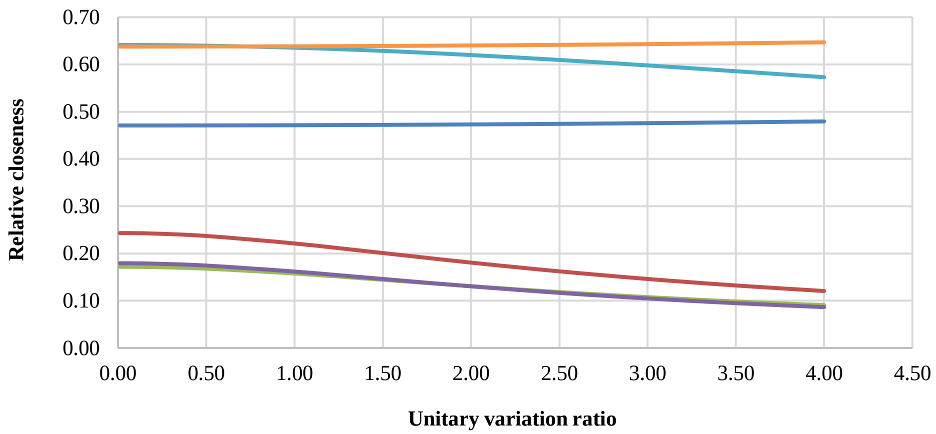
0.80
0.00 0.50 1.00 1.50 2.00 2.50 3.00 3.50 4.00 4.50
Unitary variation ratio

(b)


Relative closeness
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.00 0.50 1.00 1.50 2.00 2.50 3.00 3.50 4.00 4.50
Unitary variation ratio

(c)

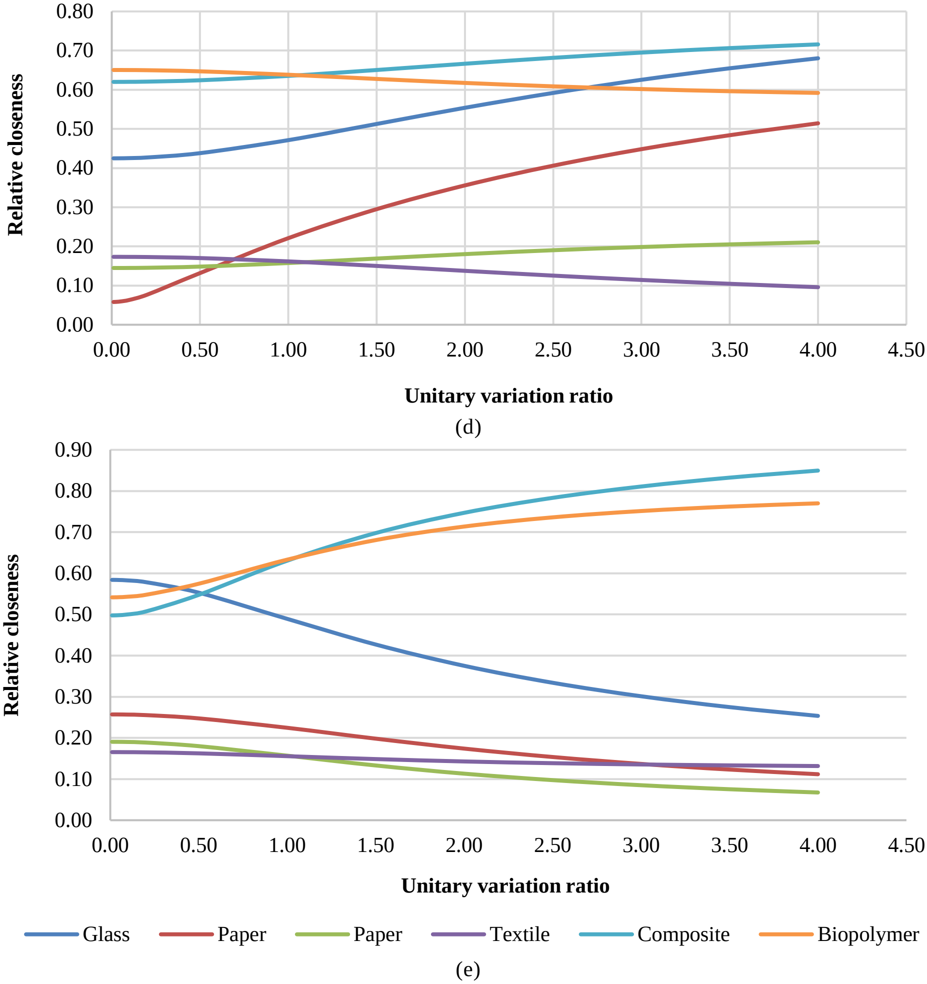


Fig. 3. Sensitivity analysis of weight distracted five parameters: (a) w_1; (b) w_2; (c) w_3; (d) w_4; (e) w_5.

However, for the tensile strength aspect, composite performs well compared to biopolymer. All the materials are having significant first distraction at 0.5 to 0.8 range. Glass shows poor relative closeness properties with a variation of weights. Fragile property of glass proves that property nature [46]. Since the value is getting higher the more, the breakability nature of glass has increased. Still, plastic is having low qualities compared to biopolymer. Even if the disturbances made influence to the data it has not affected the TOPSIS final results decision. Therefore, the biopolymer is still playing a leading role among other packaging material types.

As in the previous literature sources, changing all the parameters at the same point is more complicated. Also, the results obtaining is really hard. Therefore, it should be carried out as further development.

4. CONCLUSIONS

This paper contains results of the thermal, physical and mechanical performance of packaging materials by taking into account different criteria, which facilitates the determination of the best alternative from a set of alternatives.

Looking through the calculated values, biopolymer materials have the closest value to the ideal solution in comparison with the other materials. Therefore, as a thermal packaging material, biopolymer materials have a highly beneficial attribute over the other packaging materials. Consequently, composites compete with biopolymers because of similar structural properties. Plastics are attributed to a lower rank because of their low thermal packaging material qualities under low structural modification conditions. Therefore, biopolymer materials themselves have better packaging properties compared to other competitive comparable materials. The introduction of biopolymeric materials will lead to optimized packaging material option in the near future.

According to the investigation, TOPSIS ranking of biopolymer packaging materials has resulted in higher attributes. As stated by the TOPSIS multi-criteria decision-making technique results, biopolymer materials are better for packaging compared to other competitive materials.

Sensitivity analysis results have been more deepened, sharpened and confirmed with the present model behaviors. Also, it has been behaved according to the previous literature theoretical behavior too. Therefore, by reviewing all obtained results we can conclude that the imposed TOPSIS method on package material analysis has given more practicable and consistent data with respect to the sensitivity analysis. Therefore, in the pathway of developing a packaging material, the decision of TOPSIS has proven that biopolymer has a higher potential than other present packaging material that is available in the industry and this final assessment was further confirmed by the results of sensitivity analysis.

REFERENCES

[1] Ramos M., Valdes A., Beltran A., Garrigós M. Gelatin-based films and coatings for food packaging applications. *Coatings* 2016:6(4):41. doi:10.3390/coatings6040041
[2] Marsh K., Bugusu B. Food Packaging – Roles, Materials, and Environmental Issues. *Journal of Food Science* 2007:72(3):39–55. doi:10.1111/j.1750-3841.2007.00301.x
[3] Zihare L., Blumberga D. Market Opportunities for Cellulose Products From Combined Renewable Resources. *Environmental and Climate Technologies* 2017:19(1):33–38. doi:10.1515/rtuect-2017-0003
[4] Ivankovic A., Zeljko K., Talic S., Martinovic Bevanda A., Lasic M. Biodegradable Packaging in the Food Industry. *Journal of Food Safety and Food Quality* 2017:68(2):23–52.
[5] Gómez-Estaca J., Gavara R., Catalá R., Hernández-muñoz P. The Potential of Proteins for Producing Food Packaging Materials : A Review. *Packaging Technology and Science* 2016:29(4–5):203–224. doi:10.1002/pts.2198
[6] Blunden S., Wallace T. Tin in canned food : a review and understanding of occurrence and effect. *Food and Chemical Toxicology* 2003:41(12):1651–1662. doi:10.1016/S0278-6915(03)00217-5
[7] Zhou J., Liu S., Qi J., Zhang L. Structure and Properties of Composite Films Prepared from Cellulose and Nanocrystalline Titanium Dioxide Particles. *Journal of Applied Polymer Science* 2005:101(6):3600–3608. doi:10.1002/app.22650
[8] ASTM C 1048. Standard Specification for Heat-Treated Flat Glass-Kind HS, Kind FT Coated and Uncoated Glass, 2004.
[9] ASTM. Standard Test Methods for Water Vapor Transmission of Materials. *ASTM Annual Book of ASTM Standards* 2000:907–914.
[10] RaheemD. Application of plastics and paper as food packaging materials – An overview. *Emirates Journal of Food and Agriculture* 2012:25(3):177–188. doi:10.9755/ejfa.v25i3.11509
[11] Cho B., Ryu J., Song B. Pilot Study on the Manufacture of Kraft Paper from OCC Pilot Study on the Manufacture of Kraft Paper from OCC. *Journal of Korea Technical Association of the Pulp and Paper Industry* 2008:40(5).

[12] Tutus A., Karatas B., Cicekler M. Pulp and Paper Production from Hemp by Modified Kraft Method. Presented at the 1st International Mediterranian Science and Engineering Congress, Adana, Turkey, 2016.

[13] Costa J. L., Legrand V., Freour S. Durability of Composite Materials under Severe Temperature Conditions : Influence of Moisture Content and Prediction of Thermo-Mechanical Properties During a Fire. *Journal of Composites Science* 2019:3:55. doi:10.3390/jcs3020055

[14] Raut I., et al. Comparative Study on the Behavior of Virgin and Recycled Polyolefins – Cellulose Composites in Natural Environmental Conditions. *Journal of Composites Science* 2019:3(2):60. doi:10.3390/jcs3020060

[15] Halden R. U. Plastics and Health Risks. *Annual Review of Public Health* 2010:31:179–194. doi:10.1146/annurev.publhealth.012809.103714

[16] Poustka J., et al. Acrylonitrile in Food Contact Materials – Two Different Legislative Approaches : Comparison of Direct Determination with Indirect Evaluation Using Migration into Food Simulants. *Chezh Journal of Food Sciences* 2007:25(5):265–271. doi:10.17221/678-CJFS

[17] Tokiwa Y., et al. Biodegradability of Plastics. *International Journal of Molecular Sciences* 2009:10(9):3722–3742. doi:10.3390/ijms10093722

[18] Almaadeed M. A., et al. Mechanical, sorption and adhesive properties of composites based on low-density polyethylene filled with date palm wood powder. *Materials & Design* 2014:53:29–37. doi:10.1016/j.matdes.2013.05.093

[19] Gicevska J., Bazbauers G., Repele M. Ecodesign of Liquid Fuel Tanks. *Environmental and Climate Technologies* 2011:6(1):17–22. doi:10.2478/v10145-011-0002-6

[20] Sarker M., et al. Chemical Products Produced from High-Density Polyethylene (HDPE) Waste Plastic. *International Journal of Material Science* 2012:2(3):56–62.

[21] Chen G., Patel M. K. Plastics Derived from Biological Sources : Present and Future: A Technical and Environmental Review. *Chemical Reviews* 2011:112(4):2082–2099. doi:10.1021/cr200162d

[22] Hadad D., Geresh S., Sivan A. Biodegradation of polyethylene by the thermophilic bacterium *Brevibacillus borstelensis*. *Journal of Applied Microbiology* 2005:98(5):1093–1100. doi:10.1111/j.1365-2672.2005.02553.x

[23] Fabbri C., Bietti M., Lanzalunga O., Chimica D. Generation and Reactivity of Ketyl Radicals with Lignin Related Structures. On the Importance of the Ketyl Pathway in the Photoyellowing of Lignin Containing Pulps and Papers. *Journal of Organic Chemistry* 2005:70(7):2720–2728. doi:10.1021/jo047826u

[24] Cazón P., et al. Polysaccharide-based films and coatings for food packaging: A review. *Food Hydrocolloids* 2017:68:136–148. doi:10.1016/j.foodhyd.2016.09.009

[25] Chua H., Yu P. H. F., Ma C. K. Accumulation of Biopolymers in Activated Sludge Biomass. *Applied Biochemistry and Biotechnology*1 1999:78(1–3):389–399. doi:10.1385/ABAB:78:1-3:389

[26] Salgado P. R., Ortiz S. E. M., Petruccelli S., Mauri A. N. Biodegradable sunflower protein films naturally activated with antioxidant compounds. *Food Hydrocolloids* 2010:24(5):525–533. doi:10.1016/j.foodhyd.2009.12.002

[27] Roy N., Saha N., Saha P. Biodegradable Hydrogel Film for Food Packaging Centre of Polymer Systems. Presented at the *4th WSEAS International Conference on Energy and Development*, Corfu Island, Greece, 2011.

[28] Quilter H. C., Hutchby M., Davidson M. G., Jones M. D. Polymerisation of a terpene-derived lactone: A bio-based alternative to ϵ-caprolactone. *Polymer Chemistry* 2017:5:833–837. doi:10.1039/C6PY02033J

[29] Weber C. J. Biobased Packaging Materials for the Food Industry: Status and Perspectives. *Food Science &Technology* 2000:5:16–20.

[30] Tutak D., Keskin B., Abubakr S., Fleming P. D. Water Vapor Permeability (Wvtr) Of Packaging Cartons In Water Vapor Permeability (Wvtr) Of Packaging Cartons in Extreme Hot. Presented at the *6th International Printing Technologies Symposium*, Istanbul, Turkey, 2019.

[31] Ponnambalam V., Poon S. J., Shiflet G. J. Fe-based bulk metallic glasses with diameter thickness larger than one centimeter. *Journal of Materials Research* 2004:19(5):1320–1323. doi:10.1557/JMR.2004.0176

[32] Elsabee M. Z., Abdou E. S. Chitosan-based edible films, and coatings : A review. *Materials Science and Engineering: C* 2013:33(4):1819–1841. doi:10.1016/j.msec.2013.01.010.

[33] Benavides S., Villalobos-Carvajal R., Reyes J. E. Physical, mechanical and antibacterial properties of alginate film: Effect of the crosslinking degree and oregano essential oil concentration. *Journal of Food Engineering* 2012:110(2):232–39. doi:10.1016/j.jfoodeng.2011.05.023

[34] Pang J., et al. Fabrication of Cellulose Film with Enhanced Mechanical Properties in Ionic Liquid 1-Allyl-3-methylimidazolium Chloride (AmimCl). *Materials* 2013:26(6):1270–1284. doi:10.3390/ma6041270

[35] Stirna U., Fridrihsone A., Misane M., Vilsone D. Rapeseed Oil as Renewable Resource for Polyol Synthesis. *Environmental and Climate Technologies* 2011:6(1):85–90. doi:10.2478/v10145-011-0012-4

[36] Priedniece V., Spalvins K., Ivanovs K., Pubule J., Blumberga D. Bioproducts from potatoes. A review. *Environmental and Climate Technologies* 2017:21(1):18–27. doi:10.1515/rtuect-2017-0013

[37] Nafchi A. M., Moradpour M., Saeidi M., Alias A. K. Thermoplastic starches: Properties, challenges, and prospects. *Starch* 2013:65(1–2):61–72. doi:10.1002/star.201200201

[38] Qi H., Chang C., Zhang L. Properties and applications of biodegradable transparent and photoluminescent cellulose films prepared via a green process. *Green Chemistry* 2009:11(2):177–184. doi:10.1039/B814721C

[39] Erhardt D., Tumosa C. S. Chemical Degradation of Cellulose in Paper over 500 Years. *Restaurator* 2005:26(3):151–158. doi:10.1515/rest.2005.26.3.151

[40] Shatalov I., Shatalova A., Shleikin A. Developing Of Edible Packaging Material Based On Protein Film. *Football* 2014:298–301.
[41] Popa S., Sorina B., Simulescu V. Collagen films obtained from collagen solutions characterized by rheology. *Materiale Plastice* 2017:54(2):359–361.
[42] Abugoch L. E., et al. Food Hydrocolloids Characterization of quinoa protein chitosan blend edible films. *Food Hydrocolloids* 2011:25(5):879–886. doi:10.1016/j.foodhyd.2010.08.008
[43] Rawdkuen S., Suthiluk P., Kamhangwong D., Benjakul S. Properties of gelatin-based film incorporated with catechin-lysozyme. *Chemistry Central Journal* 2012:6:131. doi:10.1186/1752-153X-6-131
[44] Aider M. Chitosan application for active bio-based films production and potential in the food industry : Review. *LWT – Food Science Technology* 2010:43(6):837–842. doi:10.1016/j.lwt.2010.01.021
[45] Muizniece I., Blumberga D. Thermal Conductivity of Heat Insulation Material Made from Coniferous Needles with Potato Starch Binder. *Energy Procedia* 2016:95:324–329. doi:10.1016/j.egypro.2016.09.014
[46] Krohling R. A., Pacheco A. G. C. A-TOPSIS – An approach based on TOPSIS for ranking evolutionary algorithms. *Procedia Computer Science* 2015:55:308–317. doi:10.1016/j.procs.2015.07.054
[47] Li P., Qian H., Wu J., Chen J. Sensitivity analysis of TOPSIS method in water quality assessment: I. Sensitivity to the parameter weights. *Environmental Monitoring and Assessment* 2012:185(3):2456–1461. doi:10.1007/s10661-012-2723-9
[48] Swain P. T. R., Biswas S. Selection of Materials Using Multi-Criteria Decision Making Method by Considering Physical and Mechanical Properties of Jute/Al_2O_3 Composites. *Applied Mechanics and Materials* 2014:592–594:729–733. doi:10.4028/www.scientific.net/AMM.592-594.729
[49] RISE. Roadmaps toward the future bioeconomy – the vital role of the forest industry. Stockholm: Research Institutes of Sweden, 2015.
[50] Rawlings J. O., et al. Applied Regression Analysis: A Research Tool. New York: Springer, 1998.
[51] Zavadskas E. K., et al. Development of TOPSIS method to solve complicated decision-making problems: An overview ofdevelopments from 2000 to 2015. *International Journal of Information technology and Decision Making* 2016. doi:10.1142/S0219622016500176
[52] Vinodh S., Prasanna M., Prakash N. H. Integrated Fuzzy AHP – TOPSIS for selecting the best plastic recycling method : A case study. *Applied Mathematical Modelling* 2014:38(19–20):4662–4672. doi:10.1016/j.apm.2014.03.007
[53] Kaya T., Kahraman C. Expert Systems with Applications An integrated fuzzy AHP – ELECTRE methodology for environmental impact assessment. *Expert Systems with Applications* 2011:38(7):8553–8562. doi:10.1016/j.eswa.2011.01.057
[54] Miranda G., Berna A., Mulet A. Dried-Fruit Storage: An Analysis of Package Headspace Atmosphere Changes. *Foods* 2019:8(2):56. doi:10.3390/foods8020056