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EDITED BY
Tripti Agarwal,
National Institute of Food Technology Entrepreneurship and Management, India

REVIEWED BY
Rasappa Viswanathan,
Indian Council of Agricultural Research (ICAR), India
Gunjan Mukherjee,
Chandigarh University, India

*CORRESPONDENCE
Irene S. Fahim
✉ isamy@nu.edu.eg

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Towards a circular economy: fabrication and characterization of biodegradable plates from sugarcane waste

Yara Hossam and Irene S. Fahim*

Smart Engineering Systems Research, Industrial Engineering Department Director, Giza, Egypt

Bagasse pulp is a promising material to produce biodegradable plates. Bagasse is the fibrous residue that remains after sugarcane stalks are crushed to extract their juice. It is a renewable resource and is widely available in many countries, making it an attractive alternative to traditional plastic plates. Recent research has shown that biodegradable plates made from Bagasse pulp have several advantages over traditional plastic plates. For example, they are more environmentally friendly because they are made from renewable resources and can be composted after use. Additionally, they are safer for human health because they do not contain harmful chemicals that can leach into food. The production process for Bagasse pulp plates is also relatively simple and cost-effective. Bagasse is first collected and then processed to remove impurities and extract the pulp. The pulp is then molded into the desired shape and dried to form a sturdy plate. Overall, biodegradable plates made from Bagasse pulp are a promising alternative to traditional plastic plates. They are environmentally friendly, safe for human health, and cost-effective to produce. As such, they have the potential to play an important role in reducing plastic waste and promoting sustainable practices. Over the years, the world was not paying strict attention to the impact of rapid growth in plastic use. As a result, uncontrollable volumes of plastic garbage have been released into the environment. Half of all plastic garbage generated worldwide is made up of packaging materials. The purpose of this article is to offer an alternative by creating bioplastic goods that can be produced in various shapes and sizes across various sectors, including food packaging, single-use tableware, and crafts. Products made from bagasse help address the issue of plastic pollution. To find the optimum option for creating bagasse-based biodegradable dinnerware in Egypt and throughout the world, researchers tested various scenarios. The findings show that bagasse pulp may replace plastics in biodegradable packaging. As a result of this value-added utilization of natural fibers, less waste and less of it ends up in landfills. The practical significance of this study is to help advance low-carbon economic solutions and to produce secure bioplastic materials that can replace Styrofoam in tableware and food packaging production.

KEYWORDS
bagasse, plastics, sugarcane, food packaging, biodegradable, plates

1. Introduction

Food packaging has developed into an essential part of successful food companies that provide fast food, prepared meals, portable beverages, and snacks, among other things (Imam et al., 2012). The world's population was forecast to be 7.7 billion in 2019. By 2050, it is predicted to increase to 9.7 billion (Ncube et al., 2021), with an expected 50% increase in the need for food supply worldwide (Guillard et al., 2018). The increase in demand for food production and, as a result, the use of food packaging materials are both driven by the expansion in the world's population. Food packaging protects food from environmental dangers that can be classified as physical, chemical, and biological (Jacob et al., 2020). Various varieties have been used in various shapes, including food packaging. They have unique qualities, are highly functional, and are reasonably inexpensive (Directive (EU) of the European Parliament, 2019). Plastics have a solid weight-to-strength ratio. This leads to packing containers using a minimum amount of materials, with the packaging material making up to 3% of the packaged product's weight (Andrady and Neal, 2009). Packaging contributes the most to worldwide plastic trash, accounting for over 50% of the total weight (Dahl, 2018). Compared to middle- and low-income nations, high-income countries have produced more plastic garbage per person because their customers can afford a broader range of plastic-packaged goods. However, with the introduction of mechanisms for managing plastic trash, the amount of poorly managed plastic garbage from industrialized nations is starting to decrease. Due to inefficient or nonexistent plastic waste management systems, up to 90% of plastic garbage is improperly disposed of, making middle- and low-income nations the primary producers of global plastic pollution (Ritchie and Roser, 2018). The market for packaged foods worldwide is anticipated to expand at a CAGR of 7.43% over the forecast period (2021–2026).

Food packaging's primary purpose is maintaining food quality and guaranteeing customer safety. The usage of single-use plastics in packaging has increased considerably over the past several decades. As a result, more plastic packaging trash is being produced and damaging our environment. It is crucial to progress towards a more circular economy and increase the sustainability of our food systems, both of which rely heavily on packaging. The packaging industry uses the most plastics (around 40%), and plastic packaging accounts for over 60% of post-consumer plastic waste in the EU. Most of this garbage is only used once before being thrown away (European Plastics Strategy, 2018). Less than 5% of plastic packaging trash is recycled globally; the remainder is dumped, burned, or cremated (Heinrich Böll Foundation, 2019). The amount of packaging garbage produced in Egypt is increasing, with each EU resident producing 173 kg of packaging waste in 2017. This is an increase of almost 10% from 2007. Regarding market share value, two-thirds of all European packaging comprises food and beverage packaging (Eunomia, COWI, 2020).

Paper and plastic are the most often used packaging materials for food. A global estimate puts the amount of plastic used in packaging at 280 metric tons (Paine, 2012). The most significant consumer of plastics is the packaging industry, where polymers account for over 90% of flexible packaging and just 17% of rigid packaging. In order to increase product protection and lower the cost of plastic containers, barrier resins are typically used in modifications. Remaining monomers in plastics and paper, stabilizers, plasticizers, and condensation-related components like bisphenol A, raise health risks (BPA). Some of these worries are supported by research utilizing extremely high consumption levels, while others lack any supporting evidence. Estrogen, thyroid, and testosterone functioning can be impacted by the active form of BPA, which binds to steroid receptors (Science Daily report, 2011). National and international regulatory authorities, like the Food and Drug Administration (FDA) and the European Food Safety Authority (EFSA), thoroughly examine and control the compounds used to create plastics and other packaging materials to protect public safety. Any material that can migrate into food is categorized as an indirect food additive and is subject to laws. Bisphenol A will no longer be used in food packaging for children under three starting in 2013, according to the Swedish government (The State of Food and Agriculture, 2012). The consequences of chemicals like perfluorinated compounds (PFC), often used in food packaging, were also the subject of recent research. They can be found in stain-resistant carpets, microwave popcorn bags, and Teflon cookware. These substances may reduce the protection that young infants receive from vaccinations. Children who were exposed to perfluorinated compounds (PFCs) in the womb or during the first few years of life had poorer tetanus and diphtheria immunity, according to Grandjean et al. (2012). According to figures worldwide, 2.01 billion tons of municipal solid waste (MSW) are produced yearly, with 0.74 kilograms of garbage produced per person on average (kg). In high-income countries, the amount of garbage produced per person is predicted to rise by 19%, whereas it will rise by at least 40% in low- and middle-income nations. By 2050, it is predicted that 3.40 billion tons of waste will be accumulated (IBRD – financial statements, n.d.). Therefore, solid waste management has become a severe issue in both developed and developing countries (Abdel-Shafy and Mansour, 2018). The global market for recycled paper has been around for 30 years. Round, irregular, oval, tray, current design, and shell-shaped plates are among the plate shapes.

Disposable plastic or paper plates covered with plastic are not as environmentally beneficial as compostable plates. Compostable plates, made of organic materials, are ideal for large gatherings like parties, picnics, and barbecues where using reusable ceramic plates is impracticable. Compostable plates are still considered single-use items even if they biodegrade instead of breaking down in landfills. The market for biodegradable tableware is divided into five central regions based on geographical Analysis: North America, Europe, Asia Pacific, Latin America, and the Middle East and Africa. Due to significant market players who produce and sell biodegradable tableware in the area, the European market is predicted to have the most significant market share. In addition, the area is setting the bar for sustainability with its "New EU Directive for Single-Use Plastics" program. Due to the area's rapid industrialization, changing consumer tastes, increased health consciousness, and pollution-reduction efforts, the Asia Pacific region is expected to have the market's fastest growth over the projected period. The increased demand for biodegradable dinnerware is also a result of the region's growing awareness of environmentally friendly products, particularly in nations like China, India, and Japan.

Bioplastic is any plastic that is predominantly made from organic, renewable sources including starch, tapioca, milk, and vegetables and that can biodegrade quickly. By transforming the sugars (or another monomer) found in plants or animals into polymer plastic, bioplastics are created. Parable, dextrose is extracted from milled maize during the production of polylactic acid (PLA). In large vats, bacteria, or yeast ferment dextrose to produce lactic acid, which serves as a monomer for the creation of polylactic acid. Lactic acid is transformed into lactide oligomers during this production. PLA is created by joining the lactides. Several different types of polymers fall under the category of bioplastics, whose number is constantly growing as a result of new discoveries and efforts to enhance their properties. Their varieties are of Corn-based starch-based bioplastics are straightforward biomaterials. Cellulose-based—Made from cellulose esters and derivatives of cellulose. Protein-based—Made of proteins including milk, casein, and wheat gluten. Polylactic acid (PLA), polyhydroxyvalerate (VLA), polyhydroxyhexanoate (PHH), and other biobased polyesters are examples of aliphatic polyesters. Organic polyethylene is produced by the fermentation of unprocessed crops like sugar cane and maize (Bioplastics: Their advantages and concerns - researchgate, n.d.).

Bioplastics are used in a wide range of industries, including packaging, food, consumer electronics, cosmetics, cars, agriculture/horticulture, toys, textiles, and a number of other expanding areas. The market for bioplastics is now dominated by rigid packaging and consumer goods made mostly of biobased PET and PUR. The packaging market will be dominated by bioplastic goods, which will account for more than 53% of the world's total production of bioplastics (1.14 million tons). In 2017, 880,000 tons of bioplastics were expected to be produced globally. 1–8 million tons of bioplastics are projected to be produced in 2022. An expanding number of sectors, including packaging, consumer products, electronics, automotive, and textiles, are using bioplastics. As of 2020, packaging accounted for 47% (0.99 million tons) of the market for bioplastics, which is still the largest market. Depicts percentages of usage in the bioplastic sector during the previous several years as of 2020. The illustration demonstrates how bioplastic materials used in packaging applications are intended to protect items from the environment while maintaining their quality. The food processing industry produces most of the packaging for uses in bioplastics such as food and beverage, healthcare, cosmetics, and other applications. In order to provide safe and affordable transportation and the provision of items to clients in excellent condition, food packaging combines the art, science, and technology of confinement (Overview of bioplastic introduction and its applications in product, n.d.).

The biodegradable tableware market is further divided into the following groups according to the region:

1. North America (U.S. & Canada) Market size, Y-O-Y growth & Opportunity Analysis
2. Latin America (Brazil, Mexico, Argentina, and Rest of Latin America) Market Size, Y-O-Y Growth & Opportunity Analysis
3. Europe (U.K., Germany, France, Italy, Spain, Hungary, Belgium, Netherlands & Luxembourg, NORDIC, Poland, Turkey, Russia, Rest of Europe) Market size, Y-O-Y growth & Opportunity Analysis
4. Asia-Pacific (China, India, Japan, South Korea, Indonesia, Malaysia, Australia, New Zealand, Rest of Asia-Pacific) Market size, Y-O-Y growth & Opportunity Analysis.
5. Middle East and Africa (Israel, GCC (Saudi Arabia, UAE, Bahrain, Kuwait, Qatar, Oman), North Africa, South Africa, Rest of Middle East and Africa) Market size, Y-O-Y growth & Opportunity Analysis

About 55% of the world's usage of biodegradable biopolymers occurs in Western Europe, which has the most substantial restrictions on single-use plastics. Around 25% of the world's consumption occurs in Asia and Oceania (Australia and New Zealand), followed by North America at 19% and other nations and regions at less than 1%.

Reusability solutions are now more popular across the packaging value chain due to customer demand and regulatory demands on package sustainability.1 By lowering the number of packages on the market, such methods can assist in decreasing greenhouse gas (GHG) emissions and packaging consumption. This may be done by making those packages more reusable and increasing the number of usage cycles (also known as "rotations").

Despite this, there are several barriers to expanding reusability within the present packaging value chain, most related to a lack of infrastructure, product safety, and high costs. This article explores the possible impact of reusability solutions across three dimensions to comprehend better these complexities: The economic effects of reusable solutions as opposed to alternatives (for instance, accounting for the packaging itself, handling, and costs of logistics). The effects of materials used in reusable solutions on the environment (specifically, CO_2 emissions) and the reusability system itself (emissions from item production and emissions from rotation). The social effects of the implementation of reusability systems on stakeholders (such as single-use packaging manufacturers, reusable packaging operators, retailers, and consumers). Our reusable packaging use-case scenarios considered the implications of usage cycles and overall product life cycles while concentrating on the established European alternatives (Gruenewald et al., 2023).

Bagasse is a naturally occurring product made from sugar cane. With minimum processing, manufacturers create biodegradable paper goods from it. Bagasse would wind up in a landfill if businesses did not utilize it and turn it into valuable things. Following the crushing and juice extraction of sugar cane stalks, a fibrous residue known as bagasse is left behind. Bagasse often arrives at facilities producing biodegradable products as wet pulp, which is compressed and turned into a dry pulp board. The pulp board is fed through a molding device shaped into a plate. To strengthen the material, some producers go the additional mile and combine the pulp with a substance that repels water and oil. Bamboo plants are a simple renewable material supply since they are robust, grow quickly, and do not require pesticides or watering.

Additionally, producers of biodegradable goods made from bamboo plants may gather the materials they want without really damaging the bamboo plants. Sheath, the protective outer coat of the bamboo stalk, is often used to make bamboo items. Sheaths naturally come off as part of the bamboo's natural development process. The material is gathered, cleaned, and boiled once a plant reaches maturity and sheds its sheath before being laminated into plates of the desired thickness. The sheath is formed into the proper shape without chemicals by manufacturers who press and glue it. In addition to being ecologically benign, items created from palm tree leaves also help the local economy in the tropical regions where the plants are found. Locals gather naturally falling palm tree leaves for processing. This environmentally friendly gathering method does not physically hurt the trees or cause deforestation. The cleaned, dried, and pulped leaves are then used to create a light but strong fiberboard. Artisans create multiple products from a single leaf of fiberboard using high-heat molds to shape them into biodegradable plates and bowls. Plates constructed from palm tree leaves may be fully composted because they do not need any binders or chemicals. Compostable bioplastics may be created using the starches of many plants, mainly maize and potatoes. When composted in an industrial setting, these polymers are harmless and break down into carbon dioxide, water, and biomass. Bioplastics, unlike conventional plastics, are not made from chemicals sourced from petroleum. Hence they are not a byproduct of the fossil fuel industry. However, as bioplastics need energy to be produced, there will probably still be greenhouse gas emissions unless the facility that makes the bioplastic uses only renewable energy (Murphy, 2022).

Although sugarcane bagasse is still utilized to generate energy in industrial ovens, the bagasse's worth has significantly grown due to its significance as a recycled resource. Packaging supplies and disposable dinnerware are made from sugarcane bagasse. Additionally, the paper sector has started using sugarcane bagasse fibers instead of wood fibers to make cardboard, toilet paper, and napkins (Osore and Mwero, 2019). Currently, the primary feedstock for producing bioenergy and biofuels is sugarcane bagasse (Micheal and Moussa, 2021). These uses demonstrate the potential economic and environmental value of sugarcane bagasse for the nations producing sugar (Muhamad Azani yahya, 2013). Bagasse's three main constituents are cellulose, hemicellulose, and lignin, which are heterogeneous in size and particle format. The chemical elements and sugarcane bagasse's physical and structural properties are listed in Table 1.

Egypt generates more than 16.8 million tonnes of sugarcane waste each year (Hamada, 2011). Recycling sugarcane bagasse allows Egypt to produce sustainable building materials and everyday goods. Until 1981, the majority of sugar was produced from sugarcane, but sugar beets were introduced to meet the rising local demand. Around the Upper Egypt area, cane plantations are located around Menia, Sohag, Qena, Luxor, and Aswan. Hamada estimates that Upper Egypt produces about 16 million tonnes of gross cane annually. Thus, with an annual production of 7,5 million tonnes, Egypt is regarded as the leading producer of sugar cane in the Arab world, followed by Sudan. According to the graph below, eight sugar cane factories are located close to the crops in Egypt, primarily in Upper Egypt. El Menia, Abou Korkas mill; Sohag, Gerga mill; Qena, Naga Hamadi, Deshna, and Kou's mills; Luxor, Armant mill; Aswan, Edfu, and Komombo mills are the governorates of the sugar cane mills. The ultimate objective of this research is to expand the use of plates made from sugarcane. A thorough measurement of its attributes is necessary to do this, enabling an unbiased evaluation of the composite material's response to environmental factors. The current study aimed to evaluate the critical features of plates constructed from a bagasse pulp combination and to establish how those plates interacted with standards for plastic plates. In the study, bagasse from sugarcane was employed as an additional fiber in the production of plates. The critical contribution of this research is that sugarcane bagasse was never added to plates in the form of fibers. The test needed for the Sugar bagasse plate is Primary Aromatic Amines (PAA) in Water Extract, Analysis of amines as cleavage products of azo colorants acc. to REACH annexe XVII No. 43, 1,3-Dichloro-2-propanol (1,3-DCP) and 3-MONOCHLORO-1,2-PROPANEDIOL in Water Extract and Migration of Antimicrobial Substances.

The usage of synthetic plastic was outlawed in a number of nations, including the United Kingdom, China, Montreal, Australia, Canada, Hamburg, France, Morocco, and New York. The ultimate demise of non-renewable resources enhances consumer demand for environmentally friendly goods and increases the likelihood that bioplastics will take a larger market share. With over 65 percent (1.2 million tonnes) of the global bioplastics market in 2018, packaging continues to be the most popular use for bioplastics. Published data from 2017 indicated that 2.05 million tonnes of bioplastic were produced globally. This market is anticipated to grow by 20% over the next 5 years, reaching roughly 2.44 million tonnes in 2022, as bioplastic production and consumption have been steadily rising in countries all over the world (Philip et al., 2015). A feasible raw source for making biodegradable plastics is sugarcane waste, or bagasse. Worldwide, 130 nations generate 77% of sugar cane; 191 nations are listed as sugar producers (Jamal, 2016). Because there was a lack of understanding of the dangers to the environment, bagasse waste was burnt in fields, which resulted in significant contamination.

Instead of burning it, bagasse is a highly competitive substitute that should be considered when making bioplastics. After the juice is extracted from the sugar cane, a substance made of organic sugar cane fiber called bagasse is left behind (Malte and Abhaya, 2013). These fibers mostly consist of cellulose, hemicellulose, lignin, and pectin. Bagasse may be chemically altered and has a range of

TABLE 1 The properties of sugar bagasse (Micheal and Moussa, 2021).

Chemical components		physical properties		structure properties	
components	composition %	diameter (μm)	10-34	Tensile strength (Mpa)	180-290
Glucose	19.5	Length (mm)	0.8-2.8	Young's Modulud (Gpa)	15-19
Xylose	10.5				
Arabinose	1.5	Aspect ratio (1/d)	76	Failure Strain (%)	1-5
Galactose	0.55				
lignin	9.91				
Organo Solubles	2.7	Moisture content (%)	49	Density (Kg/m^3)	880-270
Reducing sugars	1.85				
Uronic acids	1.91				
Ash	1.6				
Cellulose	50				
Total hexoses	20.04				
Total pentoses	12				

unusual physical characteristics. Additionally, the price of extraction, chemical modifications, and other bagasse pre-treatments is low. Bagasse fibers improve the final tableware's mechanical attributes, such as tensile strength, flexure strength, flexure modulus, hardness, and impact strength (Ravi et al., 2015). The use of bagasse in its cut, dried form without wetting was found to significantly reduce its mechanical properties. The ability of water to reduce the gummy nature of bagasse and to wash away any attached particles on the surface is thought to be the cause of this. Another treatment method is called "silane treatment"; it has been demonstrated to enhance fiber surface area, making it striate-like, and to improve composite qualities with regard to fiber adhesion. Water absorption also reduced after treatment, further enhancing adhesion. This reduces the dependency of the products quality on the cultivation type of bagasse or its origin allowing the use of bagasse from different sources into the same batch production after milling and mixing.

The bagasse pulp is delivered wet in the shape of sheets and is heated to dry it out and prevent spoilage while being stored. To preserve the finished product, the production process begins by soaking the chopped bagasse pulp in 95% water (Figure 1). Oil and water repellent are then added. Both the water- and oil-resistant substances (solid content: 21.76 and 23.48%) are applied at a rate of 1%. The inclusion of an oil repellent prevents the tableware bagasse products from becoming spoiled by oily meals, while the addition of a water repellent gives the finished tableware its hydrophobic feature. A group of chemicals that lessen the surface tension of paper and prevent leakage are referred to as the water-resistant agent and the oil-resistant agent. After going through three mixing stations, a well-designed pumping system (Figure 2) is used to push the homogeneous paste to the forming molds at a temperature of 150°C and a constant pressure of 0.024 MPa over the course of 10 min (Figure 3), where it takes on its final shape. To eliminate moisture, the semi-finished product is moved from the forming molds to the drying molds. The bagasse tableware items are then sent to the trimming machine (Figure 4). Each final product shape requires a separate trimming equipment to remove any additional edges created during the production process and ensure that the final shape is symmetrical (Elkayaly et al., 2021).

2. Methodology

2.1. Materials

Sugar Bagasse plates used single-use products were selected for this study. Sugar bagasse plates were fabricated at Nile University laboratory using prototype scale machine. The main raw material is bagasse pulp which is obtained from sugar making plants after pretreatment in the plant. The process includes five key steps covering pulping, molding & drying, sterilization and edge trimming and finally packaging (Elkayaly et al., 2021). Of these products, ten samples of the plate (15 cm in diameter) were manufactured as shown in Figure 3. The type of plate selected is made of natural raw material and labeled as 100% biodegradable and compostable. In addition, the plates are labeled 100% biodegradable and compostable and marked to Intertek standards. Intertek is an approved Florida Inspection Agency, Certification Body and Evaluation Entity under the Florida Product Approval Program. Participation in an Intertek quality assurance or certification program will meet inspection requirements for Florida Product Approval. Intertek requires sugar bagasse plates to

FIGURE 2
Pumping system.

FIGURE 1
Mixing bagasse pulp.

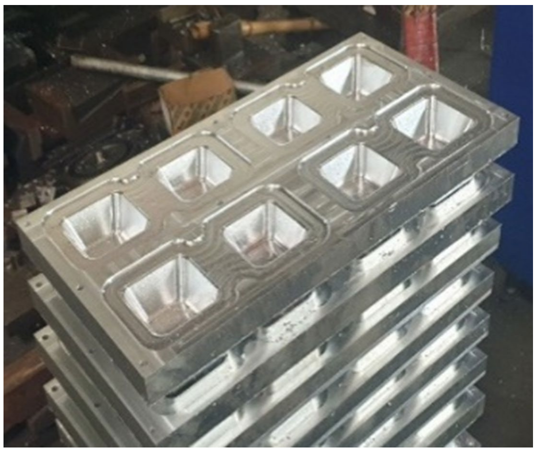

FIGURE 3
Forming.

FIGURE 4
Trimming machine.

disintegrate after 6 weeks and completely biodegrade after 6 weeks under industrial composting conditions. The manufactured plates are tested through four main tests which are Primary Aromatic Amines (PAA) in Water Extract, Analysis of amines as cleavage products of azo colorants acc. to REACH annex XVII No. 43, 1,3-Dichloro-2-propanol (1,3-DCP) and 3-MONOCHLORO-1,2-PROPANEDIOL in Water Extract and Migration of Antimicrobial Substances. These four tests represent the most important tests for any food packaging or food contact material. The manufactured plate passed all these tests.

2.2. Experimental analysis

2.2.1. Primary aromatic amines (PAA) in water extract test method

A spectrophotometric method is designed to quantitatively measure several primary aliphatic and aromatic amines, including benzidine, p-phenylenediamine, 1,5-diamino pentane, 1,6-diamino hexane, cyclohexylamine, and m-aminophenol. The 2,4-dinitrofluorobenzene (DNFB) reagent interacts with these amines to produce the desired result. The products' spectra exhibit maximal absorption at wavelengths between 355 and 357 nm and 366–377 nm, respectively, with molar absorptivity between 1.086 and 104 and 6.398 and 1.581 L/mol cm for aliphatic and aromatic primary amines, respectively. Furthermore, beer's law is observed for each of the amines mentioned above in the concentration ranges of 0.25–8.0, 1.0–10, 0.25–2.50, 1.0–8.0, 2.0–20, 1.0–12.0, and 1.0–10.0 g/mL, and the mean per cent recoveries ranged between 97.8 and 103.3% with precision (RSD) better than 5.5% for all the amines under study. Additionally, the mechanism for the DNFB-amine products has been presented, and the stability constant has been discovered.

2.2.2. Analysis of amines as cleavage products of azo colorants

The plates manufactured are analyzed for their amines as cleavage products of azo colorants. Marketing textiles colored with azo dyes capable of reductively breaking carcinogenic aromatic amines is prohibited under the current environmental standards governing textile goods. Seven azo dyes, whose chemical makeup controls how much of them split aromatic amines like benzidine, are examined in this study. Seven widely available azo dyes that include aromatic amines were chosen for testing. These contained the potentially harmful colors Acid Red 85 and Direct Blue 6, which could reductively break the carcinogenic substance benzidine. Ponceau SS, Sudan II, and Disperse Yellow 7 are three of the remaining five azo dyes that can split both p-phenylenediamine and aniline, but Mordant Orange 1 and Disperse Orange 3 can only split p-phenylenediamine. Depending on the parameters of the reduction process (for example, in the HPLC technique, 104 g/kg of dye for a reduction in NaOH, and 41 g/kg of dye for a reduction in acetate buffer), the amount of benzidine split from Acid Red 85 and Direct Blue 6 was analyzed. The preliminary investigation of the amine content in the materials under study using the spectrophotometric technique was successful. The entire number of amines counted as aniline can be found through spectrophotometric Analysis. Using high-performance liquid chromatography, amines produced from azo dyes may be thoroughly analyzed qualitatively and quantitatively (Andrady and Neal, 2009).

Azo colorants are a subset of organic colorants and make up the majority of them. A total of 10,000 commercially accessible goods (for coloring) contain azo colorants, which are available in more than 3,000 single azo colorants. Azo dyes and azo pigments are two categories into which azo colorants can be separated. Although they share some characteristics, the two groups often have quite distinct physio-chemical properties and hence, uses. The current survey includes members of both categories. Due to their significant variances, it is crucial to make a distinction and treat the two groups differently. The azo colorants are used to tint polymers, leather, textiles, cosmetics, and food items as well as to produce paints and lacquers, print materials, and pharmaceuticals. As a result, the azo colorants have a very wide range of items that they may be utilized in, such as plastic bowls, T-shirts, hair colors, and ballpoint pens. Because they are already regulated, azo colorants used and consumed in the pharmaceutical, cosmetic, and food sectors.

A few physio-chemical characteristics that the azo colorants have in common include low vapour pressures and absorption maxima in the visible and UV light spectrum. The non-ionic dyes and pigments have large octanol–water partition coefficients (log Kow 3 to 8) and are only weakly soluble in water. The ionic dyes, in contrast, differ in that they have low partition coefficients (−3 to 2.5) and are very soluble in water. Azo colorants have a huge range of toxicological characteristics. Even though many azo dyes are not carcinogenic, certain azo colorants and all azo dyes are among the first chemical substances linked to human cancer.

Azo colorants are chemicals that include one or more chromophoric groups in their chemical structure and may color a variety of materials by selective light reflection or transmission. Azo colorants can be either azo pigments or azo dyes. Azo pigments come in a variety of hues, including greenish yellow, orange, red, violet, and brown. While differing hues mostly depend on physical characteristics, colors mostly depend on chemical composition. However, the fact that most of them are red and none are green is a significant drawback restricting their commercial application.

According to EU standards for classifying harmful compounds, azo dyes have a relatively low acute toxicity. Material safety data sheets, which are readily available for many commercial azo dyes, include information regarding acute oral toxicity, including skin and eye irritation. The bulk of azo dyes displayed LD50 values between 250 and 2,000 mg/kg body weight, with just a few azo dyes exhibiting LD50 values below 250 mg/kg body weight (Clarke and Anliker, 1980). The reactive dyes, a significant subset of the more recent azo dyes, are represented by Remazol Black B (Reactive Black 5). A thorough investigation on the acute toxicity of this dye was conducted. The investigation revealed that the dye's LD50 was greater than 14,000 mg/kg body weight and that it had no adverse effects on the skin or eyes (Hunger and Jung, 1991). Methemoglobinemia may result from exposure to aromatic amines. The amines change the heme iron in hemoglobin from Fe(II) to Fe(III), which prevents it from absorbing oxygen. This causes recognizable symptoms such weakness and dizziness as well as cyanosis of the lips and nostrils. However, there are significant differences in how much methemoglobinemia may be caused by different aromatic amines (Ullmann: Encyclopaedia of industrial chemistry, 2020).

The structure activity link between aromatic amines and cancer risk has been studied in depth for this family of chemical compounds (Milman and Weisburger, 1994). Although the method of metabolic activation, which results in the creation of electrophilic reactants, appears to be ubiquitous, the carcinogenic potential of aromatic amines varies significantly with molecular configurations. The following general tendencies may indicate a structure–activity relationship: High carcinogenicity potential is linked to aromatic amines with two or more conjugated or fused aromatic rings. Although the risk is reduced, single aromatic or non-conjugated ring amines may also be carcinogenic. By interfering with N-hydroxylation, an aryl or alkyl group linked to the amino nitrogen can change the carcinogenic potential (Ullmann: Encyclopaedia of industrial chemistry, 2020).

The cancerous risk is often influenced by the aryl ring replacement. Aromatic rings that are replaced in the amino group's para-position are often more carcinogenic than those that are not. While sulphonic acid derivatives do not exhibit mutagenic or carcinogenic potential, substitution of a methyl or a methoxy group in para-position to the aromatic amine group frequently increases the carcinogenic potential. Industrially significant azo dyes frequently include carcinogenic aromatic amines that contain the moiety of the following: aniline, toluene, benzidine, and naphthalene. The link between exposure to aromatic amines containing the aforementioned moieties and cancer in experimental animals or people has also resulted in significant limitations or outright bans on the production and use of these substances. Several nations have prohibited the production and use of azo dyes based on any of the 22 aromatic amines. These amines are included on a list of harmful chemicals in the workplace in Germany (Ullmann: Encyclopaedia of industrial chemistry, 2020).

Almost all azo dyes that are commercially available can have a variety of impurities. During the production or storage procedures, impurities may be introduced. These amines may be present in azo dyes based on aromatic amines as manufacturing-related impurities. For instance, the production procedure for azo dyes based on benzidine or o-toluidine may have left behind benzidine or o-toluidine residues (Ullmann: Encyclopaedia of industrial chemistry, 2020).

2.2.3. 1,3-Dichloro-2-propanol (1,3-DCP) and 3-MONOCHLORO-1,2-PROPANEDIOL in water extract

At room temperature, 1,3-Dichloro-2-propanol (1,3-DCP) is a highly soluble liquid in ethanol and water. Its melting point is −4°C, and its boiling point is 174.3°C (Gangolli, 1999). At room temperature, 3-MONOCHLORO-1,2-PROPANEDIOL is a viscous liquid soluble in ethanol and water. Its boiling point of it is 221°C (Handbook of Chemistry and Physics, 2017). Both substances have a tight relationship with epichlorohydrin.

2.2.4. Migration of antimicrobial substances

Food items may get contaminated by microbes, one of the leading causes of foodborne illnesses, a significant public health issue, and a financial burden on the food business (Mangalassary, 2012; Dhanasekar et al., 2018; Ju et al., 2019). Food packed with antimicrobial protection is intended to lessen, impede, or delay the growth of harmful or spoilage bacteria in the food or the packaging material. An essential method for delivering antimicrobials to prevent the growth of bacteria at all stages, from transportation to ultimate consumption, is antimicrobial packaging (Mangalassary, 2012; Giannakourou and Tsironi, 2021). Antimicrobial compounds are included in packaging materials as part of antimicrobial packaging systems. These substances' primary goals are to prevent or slow the spread of undesirable microbes on food surfaces. They frequently transfer from the container to the surface of the food and are used as coatings on different polymeric materials or as part of the polymer mass. An antimicrobial agent's action is carried out either directly in the food by emission or slow diffusion of the antimicrobial agent from the packaging material to the food or indirectly in the food through contact of microorganisms onto the internal surface of the packaging material (Appendini and Hotchkiss, 2002; Giannakourou and Tsironi, 2021). They provide a potential active packaging technique that maintains safety and extends shelf life through controlled release throughout the food's shelf life (Zanetti et al., 2018). Additionally, when meals and packaging materials come into contact during processing or packaging, additives such as plasticizers, monomers, and oligomers in the packaging materials might transfer to the foods.

According to Kebede and Tola (2016), field and storage fungus excrete dangerous chemical compounds called mycotoxins. Both human and animal health are seriously at danger because of them (Bryden, 2012). Scientists are still concentrating on mycotoxins that have been shown to be hazardous despite the fact that hundreds of mycotoxins and other metabolites have now been identified (Miazzo et al., 2000). Ochratoxin A (OTA) is mostly produced by Aspergillus ochraceus, Aspergillus carbonarius, Aspergillus niger, and Penicillium verrucosum (Bui-Klimke and Wu, 2016). Due to its toxicity and widespread dispersion in food and feed items including coffee, cereals, date palm fruits, and spices, ochratoxin A is one of the most significant mycotoxins (Hua et al., 2014; Sun et al., 2017; Abdallah et al., 2018; El-Dawy, 2019). Deep-seated interstitial nephropathy, Balkan endemic nephropathy (BEN), and other serious disorders are all brought on by OTA in humans (Bui-Klimke and Wu, 2016). Bacillus species are spore-forming, rod-shaped, Gram-positive, aerobic or facultative anaerobic bacteria that are abundant in soil and are thought to be incredibly helpful microbes for the production of antimicrobial compounds (Amin et al., 2012). According to Thakaew and Niamsup (2013) and Shukla et al. (2018), *B. subtilis* is regarded as a key biocontrol agent for a number of mycotoxigenic and pathogenic fungi. In this investigation, two chosen strains of *Bacillus subtilis* and Aspergillus niger were evaluated in bagasse plates in the Intertek lab.

3. Results and discussion

3.1. Primary aromatic amines (PAA) in water extract

The aim of this study was the optimization of a multi-analyte method for the analysis of primary aromatic amines (PAAs) from plates to support official controls and food safety. We developed a spectrometer method for the simultaneous determination of 36 toxicologically relevant PAAs for the bagasse plates. The results showed that all the samples passed.

The optimal response conditions were achieved by studying the impact of several factors on the plate's absorption intensity. The total amount of PAA from 26 to 61 is 10 g/kg. The presence of PAAs in consumer items poses a severe health concern. Many PAAs are known to have allergenic or genotoxic effects. In contrast, others are classified as carcinogens by the German MAK Commission, the EU Regulation No. 1272/2008 (CLP Regulation), and the International Agency for Research on Cancer (IARC). The use of those azo colorants in textile and leather goods that can release the 22 mentioned PAAs is prohibited by EU Regulation No. 1907/2006 due to their health risk (REACH Regulation). Additionally, Regulation No. 1223/2009 use several PAAs in the manufacture of cosmetics. A general migration limit of 10 kg was established for FCMs for all PAAs. Additionally, the most recent update to the FCM Regulation, Commission Regulation No. 2020/1245, included a new limit of 2 kg per person for carcinogenic PAAs and referenced those specified in the REACH Regulation.

The International Agency for Research has identified several PAAs on Cancer (IARC) as potentially carcinogenic to humans (Group 2B). Other PAAs, including 2-naphthylamine, benzidine, and o-toluidine, are category-one human carcinogens and should not be found in food.2 European Union regulation has established a specified migration restriction for materials and articles of plastic material for food contact because of the possible damage to human health and consumer protection as shown in Table 2. These substances should not produce PAAs in measurable amounts greater than 0.01 mg per kilogram of food or food simulant. The total amount of emitted primary aromatic amines are subject to the LOD 3,4. The most used analytical technique for identifying PAAs in various matrices is the spectrophotometric approach, which outputs the results as aniline equivalents. Thus, dinnerware manufactured from biomass is a cost-effective, environmentally friendly, and biodegradable substitute for synthetic plastics used in food packing.

3.2. Analysis of amines as cleavage products of azo colorants

However, it is impossible to rule out the possibility that residues of these compounds exist in the product due to process impurities, raw material impurities, or accidental contamination. With an emphasis on the recalcitrance of azo dyes, their demonstrated susceptibility to azo bond reduction through different mechanisms, and the lack of data on the biodegradability of the resulting amines, the specific case of aromatic amines arising from the reduction of the azo bond of azo colorants is addressed. The development and current variety of analytical techniques used to detect aromatic amines in water samples are discussed, emphasizing the improved sophistication and sensitivity gained and pointing to specific initiatives in the direction of quick analytical techniques. The experiment demonstrates a green and sustainable transformation of natural resources into food containers with high biodegradability as shown in Table 3.

3.3. 1,3-Dichloro-2-propanol (1,3-DCP) and 3-MONOCHLORO-1,2-PROPANEDIOL in water extract

All chemicals and solvents used were analytical grade in purity and obtained from Intertek (n.d.). The plate is free of 1,3-DCP and 3-MCPD so it passes the test in water extract. Plate is free from any toxic material or cause cancer. The chemical epichlorohydrin is mutagenic and carcinogenic. Exposures may result in pulmonary oedema, a medical emergency involving fluid accumulation in the lungs. Epichlorohydrin exposure that was acute (short-term) and inhaled at work has irritated employees' eyes, respiratory systems, and skin. Humans may experience nausea, vomiting, coughing, labored breathing, lung inflammation, pulmonary oedema, and kidney lesions at high exposure levels. For the Safe Drinking Water and Toxic Enforcement Act of 1986, the Office of Environmental Health Hazard Assessment (OEHHA) is adding two compounds to the list of substances known to the State to cause cancer as shown in Table 4 (Proposition 65). The substances are 1,3-dichloro-2-propanol (1,3-DCP) and 3-MONOCHLORO-1,2-PROPANEDIOL (CAS Nos. 96–23-1 and 96–24-2, respectively) (Government of New Jersey, n.d.). The plate is free of 1,3-DCP and 3-MCPD so it passes the test in water extract.

3.4. Migration of antimicrobial substances

Regulations concerning the safety and quality of packaged food have been greatly impacted by migration. Several trials made to reach that the migration of antimicrobial substance is passed. Our aim was no make sure that there is no fungicidal or antibacterial substance movement throughout the test. So now we can prove that the plates are free and can be used. Medical professionals may also perform a tissue biopsy, in which a tiny sample of the diseased tissue is examined under a microscope or in a fungus culture in a laboratory for indications of Aspergillus. An early diagnosis of invasive aspergillosis in those with highly compromised immune systems can be made with a blood test.

Inhibitors for bacterial cell walls, such as beta-lactam medications, Fosfomycin, and vancomycin; inhibitors for protein biosynthesis, such as tetracyclines, macrolides, and aminoglycoside antibiotics; inhibitors for DNA synthesis, such as 4-quinolones; and inhibitors for RNA synthesis, such as rifampicin; are a few categories into which antimicrobial agents fall as shown in Table 5. Bagasse plates' nontoxic and environmentally friendly qualities are catching people's attention in commercial and domestic settings (Kohanski et al., 2010).

TABLE 2 Primary aromatic amines (PAA) in water extract.

No.	Parameter	CAS	Results	LoQ (μg/kg)	Requirement (μg/kg)
1	4-Aminodiphenyl	92-67-1	n.d.	2.0	ND
2	Benzidine	92-87-5	n.d.	2.0	ND
3	4-Chloro-o-toluidine	95-69-2	n.d.	2.0	ND
4	2-Naphthylamine	91-59-8	n.d.	2.0	ND
5	o-Aminoazotoluene	97-56-3	n.d.	2.0	ND
6	5-Nitro-o-toluidine	99-55-8	n.d.	2.0	ND
7	p-Chloroaniline	106-47-8	n.d.	2.0	ND
8	2,4-Diaminoanisole	615-05-4	n.d.	2.0	ND
9	4,4'-Diamino- diphenylmethane	101-77-9	n.d.	2.0	ND
10	3,3'-Dichlorobenzidine	91-94-1	n.d.	2.0	ND
11	3,3'-Dimethoxybenzidine	119-90-4	n.d.	2.0	ND
12	3,3'-Dimethylbenzidine	119-93-7	n.d.	2.0	ND
13	3,3'-Dimethyl-4,4′-di-aminodiphenylmethane	838-88-0	n.d.	2.0	ND
14	p-Cresidine	120-71-8	n.d.	2.0	ND
15	4,4′-Methylenebis- (2-chloroaniline)	101-14-4	n.d.	2.0	ND
16	4,4'-Oxydianiline	101-80-4	n.d.	2.0	ND
17	4,4'-Thiodianiline	139-65-1	n.d.	2.0	ND
18	o-Toluidine	95-53-4	n.d.	2.0	ND
19	2,4-Toluylenediamine	95-80-7	n.d.	2.0	ND
20	2,4,5-Trimethylaniline	137-17-7	n.d.	2.0	ND
21	2-Methoxyaniline	90-04-0	n.d.	2.0	ND
22	4-Aminoazobenzene	60-09-3	n.d.	2.0	ND
23	m-Phenylenediamine	108-45-2	n.d.	2.0	ND
24	Benzoguanamine	91-76-9	n.d.	2.0	5,000
25	4,4′-Methylenebis- (3-chloro-2,6-diethyl- aniline)	106,246-33-7	n.d.	2.0	50
26	p-Phenylenediamine	106-50-3	n.d.	2.0	–
27	Aniline	62-53-3	n.d.	2.0	–
28	2,4-Xylidine	95-68-1	n.d.	2.0	–
29	2,6-Xylidine	87-62-7	n.d.	2.0	–
30	3-Methoxyaniline	536-90-3	n.d.	2.0	–
31	2,6-Toluenediamine	823-40-5	n.d.	2.0	–
32	1,5-Diamino- naphthalene	2,243-62-1	n.d.	2.0	–
33	4-Ethoxyaniline	156–43-4	n.d.	2.0	–
34	3-Amino-4-methoxy- benzanilide	120-35-4	n.d.	2.0	–
35	3-Amino-4- methylbenzamide	19,406-86-1	n.d.	2.0	–
36	2-Amino-5- methylbenzoic acid	2,941-78-8	n.d.	2.0	–
37	4-Chloro-2-nitroaniline	89-63-4	n.d.	5.0	–
38	2-Aminobenzoic acid butyl ester	7,756-96-9	n.d.	2.0	–
39	2,4,5-Trichloroaniline	636-30-6	n.d.	5.0	–
40	2,4-Dichloroaniline	554-00-7	n.d.	5.0	–
41	5-Chloro-o-toluidine	95-79-4	n.d.	2.0	–

(Continued)

TABLE 2 (Continued)

No.	Parameter	CAS	Results	LoQ (μg/kg)	Requirement (μg/kg)
42	o-Phenylenediamine	95-54-5	n.d.	2.0	–
43	m-Chloroaniline	108-42-9	n.d.	2.0	–
44	o-Chloroaniline	95-51-2	n.d.	2.0	–
45	m-Toluidine	108-44-1	n.d.	2.0	–
46	p-Toluidine	106-49-0	n.d.	2.0	–
47	2-Methoxy-4-nitroaniline	97-52-9	n.d.	2.0	–
48	2-Ethoxyaniline	94-70-2	n.d.	2.0	–
49	5-Chloro-2- methoxyaniline	95-03-4	n.d.	2.0	–
50	4-Chloro-3- methoxyaniline	13,726-14-2	n.d.	2.0	–
51	5-Amino-6-methyl-1,3-dihydrobenzoimidazol-2- one	67,014-36-2	n.d.	2.0	–
52	p-Aminobenzamide	2,835-68-9	n.d.	2.0	–
53	2,5-Dichloroaniline	95-82-9	n.d.	5.0	–
54	2-Chloro-4-nitroaniline	121-87-9	n.d.	10.0	–
55	2,5-Dimethoxy-4- chloroaniline	6,358-64-1	n.d.	2.0	–
56	4-Aminotoluene-3- sulfonic acid	88-44-8	n.d.	5.0	–
57	2-Aminobiphenyl	90-41-5	n.d.	2.0	–
58	Dimethyl-2-amino- terephthalate	5,372-81-6	n.d.	2.0	–
59	2-Amino-1-naphtha- lenesulfanic acid	81-16-3	n.d.	5.0	–
60	2-Methyl-4-nitroaniline	99-52-5	n.d.	2.0	–
61	2-Nitroaniline	88-74-4	n.d.	2.0	–
	Sum of PAA #26 to #61	–	n.d.	–	10.0
	Status		passed		

4. Conclusion

The current study aimed to evaluate the critical features of plates constructed from a bagasse pulp combination and to establish how those plates interacted with the standards. In the study, bagasse was manufactured from sugarcane then the authors tested the plates to be approved. All tests are approved. Food preservation and protection against potential physical, chemical, microbiological, and other risks that may influence its quality and safety are the main goals of packaging. It was discovered that plates manufactured by the authors from bagasse pulp pass all tests for primary aromatic amines (PAA) in water extract, Analysis of amines as cleavage products of azo colorants by REACH annex XVII No. 43, migration of antimicrobial substances, and 1,3-Dichloro-2-propanol (1,3-DCP) and 3-MONOCHLORO-1,2-PROPANEDIOL in the water extract. The study of 36 toxicologically significant PAAs from plates using the multi-analyte approach to assist official controls and food safety. This essay covered the manufacture of dinnerware produced from bagasse from sugarcane. The findings demonstrate that bagasse is a better material for creating pulp dinnerware. All tests were successful, which indicates that sugar bagasse plates uphold safety criteria. The experiments demonstrate a green and sustainable transformation of natural resources into food containers with high biodegradability. The findings show that bagasse pulp may replace plastics in biodegradable packaging. As a result of this value-added utilization of natural fibers, less waste and less of it ends up in landfills. The FDA approval is what the authors are looking for.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

IF: She is responsible for setting overall research goals and objectives, designing research ideas, supervising and planning the overall research plan, provides financial support and coordinates the entire research process and reviewing and revising the original draft. YH: She is responsible for writing the original draft, collecting research papers, conducting research, responsible for compiling the findings and reviewing the results.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

TABLE 3 Analysis of amines as cleavage products of azo colorants acc. to REACH annexe XVII No. 43.

Parameter	CAS	Results
4-Biphenylamine / 4-Aminobiphenyl [3]	92-67-1	n.d.
Benzidine	92-87-5	n.d.
4-Chloro-2-methylaniline / 4-Chlor-o-toluidin	95-69-2	n.d.
2-Naphthylamine [3]	91-59-8	n.d.
4-Chloroaniline	106-47-8	n.d.
4-Methoxy-1,3-phenylenediamine / 2,4-Diaminoanisole	615-05-4	n.d.
4,4′-Methylenedianiline / 4,4’-Diaminodiphenylmethane [2]	101-77-9	n.d.
3,3’-Dichlorobenzidine	91-94-1	n.d.
3,3’-Dimethoxybenzidine	119-90-4	n.d.
3,3’-Dimethylbenzidine	119-93-7	n.d.
4,4′-Methylenedi-o-toluidine / 3,3’-Dimethyl-4,4’-Diaminodiphenylmethane	838-88-0	n.d.
6-Methoxy-m-toluidine / p-Cresidine	120-71-8	n.d.
p,p’-Methylenebis(o-chloroaniline) [2]	101-14-4	n.d.
4,4´-Oxydianiline [2]	101-80-4	n.d.
4,4’-Thiodianiline	139-65-1	n.d.
o-Toluidine	95-53-4	n.d.
4-Methyl-m-phenylendiamine / 2,4-Toluylenediamine [2]	95-80-7	n.d.
2,4,5-Trimethylaniline	137-17-7	n.d.
o-Anisidine	90-04-0	n.d.
o-Aminoazotoluene	97-56-3	*via o-Toluidin(e)*
2-Amino-4-nitrotoluene	99-55-8	*via 2,4-Toluylenediamine*
2,4-Xylidine [1]	95-68-1	n.d.
2,6-Xylidine [1]	87-62-7	n.d.
Aniline [1] as indicator for 4-AAB	62-53-3	n.d.
4-Aminoazobenzene (4-AAB)	60-09-3	*see Aniline*
Status		passed

[1]Further arylamines, which are not listed in Annex XVII of REACH.
[2]The amines can be indirectly generated during the procedure (cleavage with dithionite) from some colourants which do not contain these amines azo bound. No clear destinction between these and forbidden azo colourants which release amines can be made.
[3]4-Aminodiphenyl, 2-Naphthylamine >30 mg/kg: the test specimen product can have been coloured with colourants whose structures contain amines but not azo bound.

TABLE 4 1,3-Dichloro-2-propanol (1,3-DCP) and 3-MONOCHLORO-1,2-PROPANEDIOL in water extract.

Parameter	Results	LoQ (μg/L)
1,3-Dichloro-2-propanol (1,3-DCP) μg/L CAS: 96–23-1	n.d.	2
3-Monochloro-1,2-propandiol (3-MCPD) μg/L CAS: 96–24-2	n.d.	6
Status	passed	

TABLE 5 Migration of antimicrobial substances.

Parameter	Results
Fungicidal substances Test strain: Aspergillus niger	no migration of fungicidal substances
Antibacterial substances Test strain: *Bacillus subtilis*	no migration of antibacterial substances
Status	passed

Publisher’s note

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