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Circular economy for fashion industry: Use of waste from the food industry for the production of biotextiles

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A R T I C L E I N F O

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Eco-fashion
SDGs

A B S T R A C T

In the context of current environmental, social and economic issues, it is imperative to perform more in-depth studies on waste management and the life cycle of a product. Thus, the concept of circular economy, aimed at transforming traditional patterns of production and economic growth, is extremely important. One way to mitigate negative environmental impacts that is consistent with a circular economic system is to encourage interdisciplinarity between sectors, that is, one production sector can provide a function for waste from another. In this context, this article gathers scientific information on two sectors relevant to the global economy (textiles and food), with the aim of reusing waste from the food industry to manufacture a new textile product with added value. Specifically, the focus is on the use of bacterial cellulose from the probiotic drinks from kombucha, for the manufacture of biotextiles for fashion industry. A discussion is also presented, relating the circular economy concept to the UN Sustainable Development Goals, in order to understand which goals can be achieved with this approach.

1. Introduction

In order to achieve a more sustainable society, it is important to conduct in-depth studies and research on issues such as waste management, product life cycle assessment (LCA) and circular economy (Mak et al., 2020; Viau et al., 2020; H. Wang et al., 2020). The extremely high levels of consumption that have been reached are directly associated with the purchasing power of a region and increase in population, and as the demand for products increases so do the levels of waste generated (Yıldız-Geyhan et al., 2019; Ravindran and Jaiswal, 2016; Stanchev et al., 2017).

Minimizing the use of materials and rethinking the raw materials employed for manufacturing in order to favor recycling presents challenges for designers. Camere and Karana (2018) noted the different types of alternative materials available: 1) Materials from renewable resources, with an acquisition rate below the growth rate; 2) Recycled materials, obtained from reprocessing resources that have already been incorporated into products; and 3) Revived materials, that is, those comprised of resources discarded from industrial production flows, such as agricultural waste.

One of the most notable types of waste, globally, is that generated by the food industry (Kibler et al., 2018; Ravindran and Jaiswal, 2016). It has been estimated that in the countries of Latin America and the Caribbean, organic waste accounts for the highest proportion of the waste generated (approximately 50%), although it receives very little management (UN, 2019). However, studies have verified that food waste is a precious bio-resource that can be used to obtain various useful chemicals, materials and fuels (Garcia-garcia et al., 2019).

Along with the food industry, the fashion industry has problems associated with the generation of waste. According to Franco (2017), the textile and clothing industry is an essential consumer goods manufacturing, however, it is also considered one of the most polluting and socially challenged industries due to four specific issues: 1) non-recoverable materials and it́s blends; 2) abundant use of water; 3) use of dangerous chemicals; and 4) poor human rights record.

The textile manufacturing process is characterized by a high consumption of natural resources, fuel and a variety of chemicals, involving a long process from spinning, bleaching to dyeing, generating a significant pollutant load to the environment (Parisi et al., 2015). Due to the severe negative impacts related to the textile industry one of the main

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concerns is to achieve sustainability in the textile chain through cleaner production, thus mitigating environmental problems (Neto et al., 2019).

Bacterial cellulose (BC) is an ecologically-friendly, renewable and organic raw material (F. Sederavičiūtė et al., 2019; Shi et al., 2014) that is safe for contact with the human body, inspiring many design projects and drawing the attention of the fashion industry (F. Sederavičiūtė et al., 2019). BC or nanocellulose has unique characteristics, such as a high degree of crystallinity, tensile strength, thermal stability, biodegradability, elasticity and porosity (Machado et al., 2018).

Unlike cellulose extracted from plant cell walls, BC consists of pure cellulose and does not contain other polymers such as hemicellulose, lignin and pectin (Pigaleva et al., 2019; Reiniati et al., 2017). Researchers claim that the appearance of BC material is similar to leather and thus it represents a new type of sustainable fabric that can be manufactured from several sources (F. Sederavičiūtė et al., 2019).

It should be noted that agro-industrial waste serves as an economic substrate for the production of bacterial cellulose, and the use of red wine, beer, milk, juice and tea has been suggested as catalysts and culture medium for the production of BC material (Sharma and Bhardwaj, 2019). According to He et al. (2020)and Lin et al. (2020), rice husks, cotton fabric residues, distillery wastewater, industrial residues from citrus husk drinks and sugarcane bagasse, have also been used to increase BC production at low cost.

One way to obtain bacterial cellulose is from the production of the probiotic drink Kombucha, through the fermentation of teas belonging to the *Camellia sinensis* family and a sweetener, with the addition of a culture based on the symbiosis of bacteria and yeasts (De Filippis et al., 2018; Cardoso et al., 2020). Through this fermentation process, a membrane called SCOBY (Symbiotic Culture of Bacteria and Yeast) is formed (F. Sederavičiūtė et al., 2019). The bacterial cellulose formed in the production of Kombucha exhibits eco-friendly and sustainable properties, mainly since it is biodegradable (Camere and Karana, 2018; Costa et al., 2019; F. Sederavičiūtė et al., 2019; Yim et al., 2017).

In this context, this article aims to discuss the application of the circular economy between the segments of the food and textile industry. Because the amount of food waste generated that could be reused for the production of textiles, natural dyes or even for the production of bioenergy and wastewater treatment is abundant. Thus, through this research, it is possible to rethink the non-use of non-renewable resources such as fossil fuels, bringing information on the real possibilities of using these waste.

As a main highlight, this article analyzes the use of food waste for the manufacture of biotextiles using bacterial cellulose. This, considered an innovative resource despite its limitations, has received attention from researchers in recent years and deserves further research. Finally, it highlights the importance of linking the issues addressed in this article to the UN Sustainable Development Goals (SDGs), especially with regard to SDG 12, which aims to ensure sustainable standards of production and consumption.

2. Methodology

Since the research question seeks to understand the relationship of Circular Economy applied between the segments of the food and textile industry, an integrative literature review is conducted. An integrative review is a specific review method that summarizes past empirical or theoretical literature to provide a more comprehensive understanding of a particular phenomenon (Whittemore, 2005). An integrative literature review also is defined as a form of research that reviews, critiques, and synthesizes representative literature on a topic such that new frameworks and perspectives on the topic are generated (Torraco, 2005, 2016).

To conduct this integrative review, the databases chosen for the searches were: Scopus and ScienceDirect, and included analyzes of documents of the Food and Agriculture Organization (FAO), United Nations (UN), Ellen Macarthur Foundation (EMF), Brazilian Association of the Textile and Clothing Industry (ABIT) and H&M Foundation. Although the article focuses on the production of bacterial cellulose from food waste for the production of biotextiles, we chose to realize an understanding of the whole, including themes that legitimize the real possibility between the sectors cited with different examples, the relationship between CE and the industries and EC with SDG's. Thus, to perform the literature review, 5 combinations of search terms were selected for writing the topics. Fig. 1 exemplifies the method used to select research articles for this review.

As seen in Fig. 1, it should be noted that the peer reviewed articles

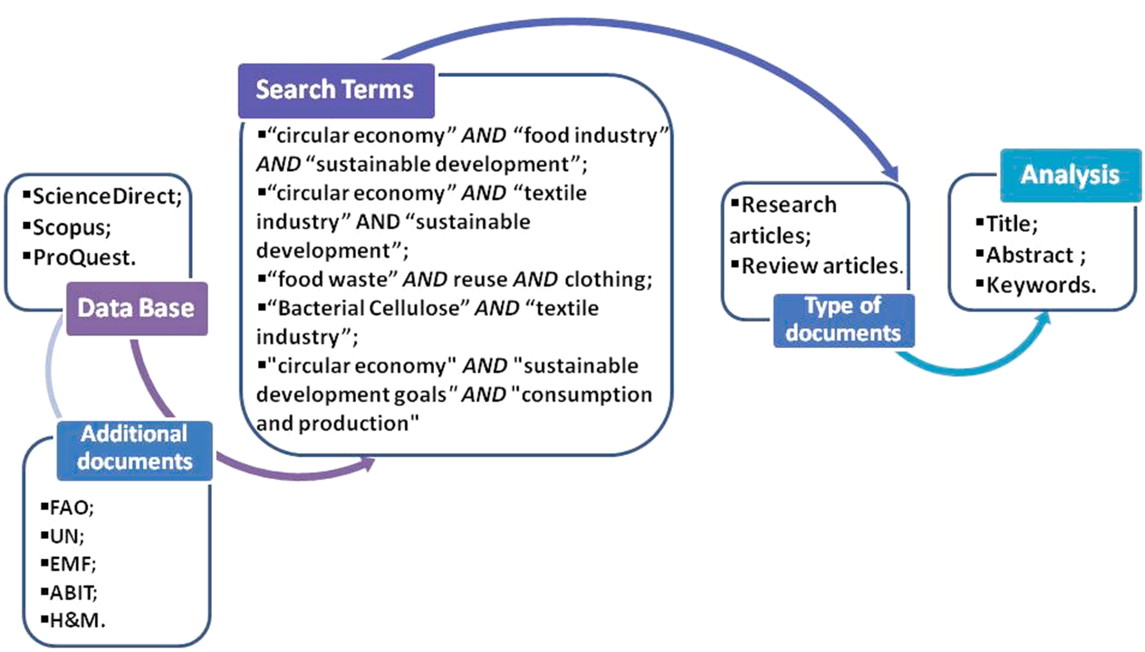

Fig. 1. Exemplification of the method used for the selection of research articles. Source: the authors.

were selected by opting for a timeframe between 2010 and 2021. Thus, inclusion and exclusion criteria were employed, which were the readings of the title, abstract and keywords, selecting only those articles that were compatible with the research theme. The complementary documents contributed to the dialog between scientific research, government agencies and companies.

Therefore, the results and discussions of this review article are structured as follows:

a) "3. Results and Discussion": presentation of the quantitative results for the realization of the review article;
b) "3.1 Circular Economy Concepts": compilation of the researched concepts on Circular Economy according to the articles found, adding the complementary documents. The objective here is to understand in general the Circular Economy;
c) "3.2. Circular Economy and the Food Industry": compilation of research on Circular Economy in the food industry according to the articles found, adding the complementary documents. The objective here is to understand the Circular Economy and the advances in the Food Industry;
d) "3.3. Circular Economy and the textile and Clothing Industry": compilation of research on Circular Economy in the Textile Industry according to the articles found, adding the complementary documents. The objective here is to understand the Circular Economy and the advances in the Textile Industry;
e) "3.4 Possibilities for reusing food waste in the textile industry": compilation of research that deals with the reuse of food waste for application in the Textile Industry according to the articles found. The objective here is to show the real possibilities, positive results and what needs to be improved for future research;
f) "3.5 Manufacture of biotextiles using bacterial cellulose for a sustainable fashion industry": compilation of specific research on the use of bacterial cellulose for the manufacture of textiles. After all the contextualization on Circular Economy, Circular Economy in the Textile and Food Industries, and the reuse of food waste for use in the Textile Industry, the use of bacterial cellulose was chosen as an example, because BC can be produced through waste food or BC can be considered the waste of a Kombucha beverage company;
g) "3.5.1 Economic aspects of biotechnology manufacturing": The objective here is to complement the results and discussions on the use of bacterial cellulose, bringing the economic aspects of its production according to the articles found;
h) "3.6 The Sustainable Development Goals and the Circular Economy": Finally, show the results and discussions on the importance of the Circular Economy to contribute to the SDGs, mainly the SDG 12, according to the articles found, adding the complementary documents.

Table 1
Comparison between the search results in the databases.

Search terms	Scopus	ScienceDirect	ProQuest
"circular economy" *AND* "food industry" *AND* "sustainable development"	60	312	351
"circular economy" *AND* "textile industry" *AND* "sustainable development"	36	154	127
"food waste" *AND* reuse *AND* clothing	4	149	103
"Bacterial Cellulose" *AND* "textile industry"	73	123	95
"circular economy" *AND* "sustainable development goals" *AND* "consumption and production"	8	305	301
Total	181	1043	977

Source: the authors.

3. Results and discussion

On searching the 5 groups of terms and using the "document type" and timeframe "2010 to 2021″ filters, 181 results were returned in the Scopus database, 1043 results in the ScienceDirect database and 977 results in the database ProQuest database. Table 1 shows a comparison between the search results.

As shown in Table 1 was totaled 2201 articles between 3 databases. For selection of articles, step 1 involved reading the title, abstract and keywords of each article. The publications which were aligned with the search theme were then selected and 1914 articles were excluded. Thus, a total of 287 articles were read in full. In step 2, a further 132 research articles that were not aligned with the proposal of this review were excluded and the exclusion of 34 articles due to the repetition existing between the Science Direct, Proquest and Scopus databases, totaling 121 articles, were considered. Fig. 2 shows the number of articles used to write each topic.

Finally, as shown in Fig. 2, 127 articles were used to write the 6 topics, 6 of which were used in more than one topic. The topics that most used articles were "3.2. Circular Economy and the Food Industry", "3.3. Circular Economy and the textile and Clothing Industry" and "3.5 Manufacture of biotextiles using bacterial cellulose for a sustainable fashion industry". This result is consistent with the purpose of the research that focuses on understanding the Circular Economy in the Food and Textile Industries, mainly around the discussion of bacterial cellulose for the production of biotextiles.

3.1. Circular economy concepts

The concept of circular economy (CE) aims to transform traditional patterns of production and economic growth, seen as linear systems, into circular dynamics that make connections between the use of resources and the waste generated, to prevent pollution and waste (Bilitewski, 2012; Buchmann-Duck and Beazley, 2020; H. Wang et al., 2020). In the face global environmental degradation and the urgent need for change, the concept has become popular around the world and this has led to the launching of national policies and strategies based on the idea of a circular economy (Buchmann-Duck and Beazley, 2020; Gupta et al., 2019; Morseletto, 2020).

In 2015, the Circular Europe Network pointed out that the concept of circular economy does not refer only to recycling, but is part of the basic 3Rs rule (Reduce, Reuse, Recycle) and makes it possible to reach the multi-R hierarchy (Rethink, Redesign, Repair, Redo and Redistribute, Recover) (Bilitewski, 2012; Jabbour et al., 2019; Kristoffersen et al., 2020). Fernandes et al. (2020) unites this with the concept of sustainable development, emphasizing that the proposal of the circular economy is to preserve natural resources, optimizing those we have and guaranteeing their availability for the future.

According to Kurdve and Bellgran (2020), Gupta et al. (2019) and H. Wang et al. (2020), a CE is a regenerative system where resource flows are minimized and speed is reduced, thus aiming at durable projects with a focus on maintenance, repair, reuse, remanufacturing, reconditioning and recycling solutions. In addition, the CE has the potential to lead to sustainable development, while decoupling economic growth from the negative consequences of resource depletion and environmental degradation (Durán-Romero et al., 2020; Jabbour et al., 2019; Morseletto, 2020). As such, CE has the potential to align eco-efficiency with economic profitability (Kiani et al., 2019; Kurdve and Bellgran, 2020). In recent years, several studies have been carried out on the concept of circular economy, which has allowed advances to be made (Gupta et al., 2019).

However, it should be noted that despite the relevance of the CE in current politics and in the economic debate, the concept remains open to interpretation (Morseletto, 2020; Suzanne et al., 2020) and currents of research from different scientific disciplines have given rise to several schools of thought regarding the circular economy (Suzanne et al.,

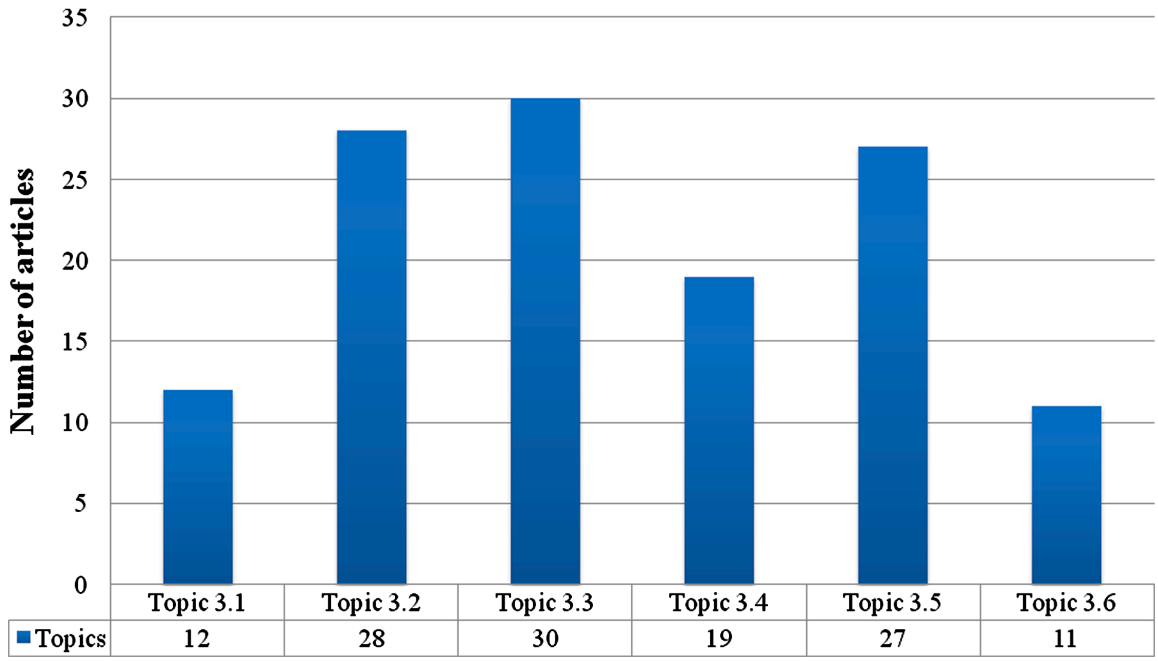

Fig. 2. Number of articles used to write each topic. Source: the authors.

2020). An example of this would be the challenge of some authors to recommend more research on the interaction between biodiversity and the circular economy, and that the defenders of the CE approach recognize that the system has limitations (Buchmann-Duck and Beazley, 2020).

Researchers at the Ellen MacArthur Foundation (EMF) are commonly cited for their work on the circular economy, as they research and describe the technical and biological inputs for a functional circular system (Buchmann-Duck and Beazley, 2020). Through the EMF website it is possible to access content about the existing schools of thought associated with the circular economy, their concepts and precursor authors (https://www.ellenmacarthurfoundation.org/).

Schools of thought like Regenerative Design by John T. Lyle, Performance Economy by Walter Stahel, Cradle to Cradle by Michael Braungart and Bill McDonough, Biomimicry by Janine Benuys and Blue Economy by Gunter Pauli are cited. Thus, it is clear that the concept of circular economy cannot be linked to a single theory or author. According to EMF, its practical applications in modern economic systems and industrial processes have acquired new dynamics since the late 1970s, led by a small number of academics, intellectual leaders and companies. Thus, the generic concept was refined and developed by several schools of thought (EMF).

3.2. Circular economy and the food industry

Research shows that the global generation of food waste (FW) is estimated at $ 1 trillion, increasing to $ 2.6 trillion when social and economic costs are considered (Slorach et al., 2019). According to the UN Food and Agriculture Organization (FAO), approximately one third of the food produced is lost every year along the journey from the field to the plate (FAO, 2018; Teigiserova et al., 2020). This waste is not only undesirable from an ethical and social point of view, it also results in the loss of natural resources, such as water, energy and fertilizers, which are necessary for the production and processing of food (Teigiserova et al., 2020; Wilts et al., 2020). In addition, food waste causes an average of 10% of greenhouse gas emissions emitted globally (Weber et al., 2020; Wilts et al., 2020).

It has been observed that the growing need for energy and materials to meet the demands of a rapidly growing and resource-intensive population is forcing a shift from a linear economy to a circular economy (Teigiserova et al., 2020). One of the essential actions required in order to achieve a circular economy is to extract value from residues, for instance, by recycling agrifood waste streams (Campalani et al., 2020; Teigiserova et al., 2020).

A survey carried out in Brazil showed that the food waste associated with tubers, for example, is 45%, which would be equivalent to 350,000 tons of sweet potatoes wasted annually (Weber et al., 2020). In the European Union, the International Panel of Experts on Sustainable Food Systems (IPES) identified that 20% of the food produced is wasted, at a cost of 143 billion euros annually, including wasted resources and environmental impact (Teigiserova et al., 2020).

Food waste is associated with issues related to the loss and/or waste of resources across the food chain, from primary production through retail and distribution to consumption in the food and hospitality sectors as well as households (Närvänen et al., 2020). It should be noted that food waste can be understood as both 'food waste', 'food loss' and 'excess food', the latter being a key factor in the current unsustainable food system (Närvänen et al., 2020). According to Sherwood (2020) and Sadeleer et al., 2020), minimizing food waste is one of the main challenges of a circular economy. Thus, projects and research studies on food waste and the CE are currently in vogue.

Many researchers recommend reusing waste for biorefineries, for example, as this is a sustainable business model and contributes to the development of the agricultural and food sectors, reduces greenhouse gas emissions and achieves the objectives of the circular economy (Teigiserova et al., 2020; Weber et al., 2020). In the case of domestic organic waste, as an example, several European cities have implemented the separation of this waste due to its energy content and the potential for its recovery through the production of biogas (Europe is the world's largest producer of biogas) (Sadeleer et al., 2020). Table 2 shows 20 current researches that address the reuse of food waste for technological applications.

Research on food waste should be encouraged, as it can play a significant role in the transition to an EC, contributing to the institutional and educational work needed to change the normative and cognitive-cultural pillars of institutions (Närvänen et al., 2020). According to Table 2 it is possible to observe the application of food waste in several sectors such as water treatment, energy production, production of

Table 2
Reuse of food waste for technological applications.

Year	Authors	Title	Application
X. 2019	Xin et al.	Insights into microbial community profiles associated with electric energy production in microbial fuel cells fed with food waste hydrolysate	Energy
H. 2019	Chen et al.	Upcycling food waste digestate for energy and heavy metal remediation applications	Energy
C. 2019	Macintosh et al.	Successful strategies for increasing energy self-sufficiency at Grüneck wastewater treatment plant in Germany by food waste co	Wastewater treatment
2019	Lee et al.	Renewable routes to monomeric precursors of nylon 66 and nylon 6 from food waste	Nylon 6 Nylon 66
2020	Ranganathan et al.	Utilization of food waste streams for the production of biopolymers	Biopolymers
F. 2020	Zan et al.	Integrated food waste management with wastewater treatment in Hong Kong: Transformation, energy balance and economic analysis	Wastewater treatment
Q. 2020	Hou et al.	Using an anaerobic digestion tank as the anodic chamber of an algae-assisted microbial fuel cell to improve energy production from food waste	Energy
X. 2020	Yang et al.	Ball-milled, solvent-free Sn-functionalisation of wood waste biochar for sugar conversion in food waste valorisation	Biochar
A. 2020	Twarogowska et al.	Upcycling of Belgian endive (Cichorium intybus var. foliosum) by-products. Chemical composition and functional properties of dietary fiber root powders	Dietary fiber
S.B. 2020	Basturk et al.	Simultaneous remediation and fertility improvement of heavy metals contaminated soil by a novel composite hydrogel synthesized from food waste	Hydrogel
B.H. 2020	Yan et al.	Bio-hydrogen and methane production from two-phase anaerobic digestion of food waste under the scheme of acidogenic off-gas reuse	Bio-hydrogen and methane
M.R. 2020	Kosseva et al.	Biopolymers produced from food wastes: a case study on biosynthesis of bacterial cellulose from fruit juices	Biopolymers
2021	Hildebrandt et al.	The circularity of potential bio-textile production routes: Comparing life cycle impacts of bio-based materials used within the manufacturing of selected leather substitutes	Leather substitutes
Z.Y. 2021	Mahssin et al.	Hydrothermal liquefaction bioproduct of food waste conversion as an alternative composite of asphalt binder	Bio-binder
Y. 2021	Lee et al.	Co-pyrolysis for the valorization of food waste and oriental herbal medicine byproduct	Biochar
C. 2021	Peng et al.	Low temperature co-pyrolysis of food waste with PVC-derived char: Products distributions, char properties and mechanism of bio-oil upgrading	Biochar and bio-oil
K. 2021	Khatami et al.	Bioconversion of food waste to volatile fatty acids: impact of microbial community, pH and retention time Kasra	Fatty acids
Z. 2021	Zhang et al.	Impact of storage duration and micro-aerobic conditions on lactic acid production from food waste	Lactic acid
X.C. 2021	Feng et al.	Enhance biological nitrogen and phosphorus removal in wastewater treatment process by adding food waste fermentation liquid as external carbon source	Wastewater treatment
A. 2021	Talan et al.	Food waste valorization: Energy production using novel integrated systems	Energy

Source: the authors.

biopolymers, among others.

Lastly, regarding the treatment of food waste, four methods can be considered: anaerobic digestion (AD), composting, incineration and landfill. Following the principles of circular economy and the waste management hierarchy, AD and composting are more favorable than incineration and landfill, highlighting the treatment of waste by anaerobic digestion, as this could save £ 251 m (pounds sterling) and 490 kt CO_2 equivalent (Slorach et al., 2019).

3.3. Circular economy and the textile and clothing industry

The textile and clothing (T&C) industry supplies essential consumer goods worldwide (Asada et al., 2020; Franco, 2017). Brazil is considered the second largest employer in the manufacturing industry and the second largest generator of the first job (ABIT, 2019). Globally, the value of the global fashion industry is US$ 3000 billion, which represents more than 2% of the gross domestic product (GDP) (Shirvanimoghaddam et al., 2020). However, it is also considered one of the most polluting and socially challenged industries globally (Asada et al., 2020; Fischer and Pascucci, 2017; Franco, 2017).

The manufacture of textiles also requires large amounts of energy and water, the use of dyes (more than 100 L of water / kg of fabric) and the use of pesticides, herbicides and fertilizers during the cultivation phase, and socio-environmental issues include effluent contamination and poor conditions of work (Asada et al., 2020; Franco, 2017; Shirvanimoghaddam et al., 2020). Therefore, it is essential to rethink the textile chain in a circular and more sustainable way (Fischer and Pascucci, 2017; Shirvanimoghaddam et al., 2020).

In the past 15 years the textile industry doubled its production, with the annual average global consumption of textiles increasing from 7 to 13 kg per person, and consumption reached 100 million tons of textiles, with more than two thirds being disposed of in landfills at the end of use and only around 15% being recycled (Shirvanimoghaddam et al., 2020). Thus, in addition to the textile and fashion industry being among the most polluting and resource-intensive industries due to the great consumption of water, energy and chemicals, thus affecting the natural environment, the growth of the global population has led to an overall increase in the manufacturing of textiles.

According to Riba et al. (2020), European countries consume large amounts of clothes and textiles as a result of the current "buy-and--throw-away" culture. To recent industrial reports, US$ 400 billion in clothing is wasted every year worldwide (Shirvanimoghaddam et al., 2020)

To significantly reduce the environmental and social footprint of the textile industry, radical changes are required, especially in the way in which textiles and clothes are designed, produced, traded, used and recirculated. Thus, fashion and textiles should be part of a circular economy, thus allowing textiles and clothes life to be extended, to retain textile fibers within a closed circuit, so that they can be used again and again (Riba et al., 2020).

In 2017, the EMF published the report "A New Textiles Economy: Redesigning Fashion's Future" showing a vision for a new long-term integrated system, based on the principles of circular economy. The objective is to transform the textile and clothing economy into an opportunity that integrates better economic, social and ecological results (Fernandes et al., 2020; To et al., 2019). This new proposal with four main ambitions has been published and is consistent with the principles of a circular economy: 1) Phase out substances of concern and microfibre release; 2) Transform the way clothes are designed, sold, and used to break free from their increasingly disposable nature; 3) Radically improve recycling by transforming clothing design, collection, and reprocessing; and 4) Make effective use of resources and move to renewable inputs (EMF, 2017).

According to recent news released by the H&M Foundation, the fast fashion chain H&M (based in Sweden), in partnership with two Hong Kong companies, HKRITA (Hong Kong Textile and Clothing Research Institute) and spinning specialist Novetex Textiles, has developed a machine called Looop (HandM Foundation, 2020). The aim of this new technology is to transform discarded clothing, often provided by the consumers themselves, into new clothing items. The entire process takes around five hours to complete.

The piece is sanitized with ozone to eliminate microorganisms and then it is transformed into fibers, which will be crushed and filtered to remove dirt. In this step, the machine adds virgin material obtained from sustainable sources (in the least amount possible) and the process does not require the use of water or chemicals such as dyes. The effort addresses the increasing volume of global clothing waste and growing concerns regarding the role played by fast fashion in this scenario (HandM Foundation, 2020).

The reuse and recycling of textiles offer a sustainable approach to reducing solid waste in landfills, reducing the production of virgin materials and energy consumption, in addition to producing a smaller environmental footprint (Riba et al., 2020; Shirvanimoghaddam et al., 2020). Table 3 shows 20 current researches that address the reuse of textile waste for technological applications. However, the recycling of post-consumer textile waste is currently a complex process, since most fabrics are produced using mixtures of different types of fibers and, due to this complexity, most fabrics today are “downcycled”, being transformed into rugs or rags (Franco, 2017).

According to Table 3, it is possible to observe the application of textile waste in various sectors such as energy production, solid fuels, thermal and acoustic insulation, glucose syrup, among others. However, it is not enough just to think about reusing waste, but also to think about not producing waste. Thus, product design is also essential to achieve EC objectives (see Fig. 3). Circular products need to be designed for life cycles and the relative sustainability of a product is strongly dependent on the choice of product materials and the production and planning processes for the entire cycle (Fischer and Pascucci, 2017; Franco, 2017).

Aiming for a circular economy through a longer product life and the reuse of materials avoids excessive waste generation and increases the total value of products (Ingulfsvann, 2020; Shirvanimoghaddam et al., 2020; Tate et al., 2019; Todeschini et al., 2017). It is also worth noting that this approach offers opportunities for innovation in product design, services, business models and establishing basic elements for a long-term resilient system (Shirvanimoghaddam et al., 2020); Todeschini et al., 2017).

According to Fischer and Pascucci (2017), in addition to rethinking materials and their forms of production, it is important to develop strategies for implementing the CE concept to carry out the transition of a company with a traditional linear system. Studies conducted in Dutch textile companies identified two paths for this transition and to manage circular material flows. The researchers defined two concepts: a) Status Quo (SQ), when companies focus on optimizing up-cycling technologies and infrastructure in their circular relationships and collaborations; and b) Product as a Service (PAS) arrangements, to indicate a focus on supplying products in service contracts.

3.4. Possibilities for reusing food waste in the textile industry

Around 20% of the total use of water, cropland and fertilizers are used to produce surplus food ending as food waste, which could have been avoided upon adopting environmental and socially responsible business models (Hildebrandt et al., 2021; Teigiserova et al., 2020). Uncontrolled decomposition of agro-industrial waste leads to extensive contamination of water, land, and air. Valorization of the wastes not

Table 3
Reuse of textile waste for technological applications.

Year	Authors	Title	Application
2019	To et al.	Recent trends in green and sustainable chemistry: rethinking textile waste in a circular economy	Green chemistry
S. 2019	Yousef et al.	A new strategy for using textile waste as a sustainable source of recovered cotton	Recovered cotton
S. 2019	Yousef et al.	A sustainable bioenergy conversion strategy for textile waste with self-catalysts using mini-pyrolysis plant	Energy
B. 2019	Zeng et al.	Development of cellulose based aerogel utilizing waste denim—A Morphology study	Aerogel
S. 2019	Islam and Bhat	Environmentally-friendly thermal and acoustic insulation materials from recycled textiles	Thermal and acoustic insulation
X. 2019	Li et al.	Efficient succinic acid production using a biochar-treated textile waste hydrolysate in an in situ fibrous bed bioreactor	Succinic acid
S. 2019	Haslinger et al.	Upcycling of cotton polyester blended textile waste to new man-made cellulose fibers	Man-made cellulose fibers
A. 2020	Bourguiba et al.	Recycled duvets for building thermal insulation	Thermal insulation
S. 2020	Yousef et al.	Sustainable green technology for recovery of cotton fibers and polyester from textile waste	Recovery of cotton fibers and polyester
A. 2020	Çay et al.	Application of textile waste derived biochars onto cotton fabric for improved performance and functional properties	Functional textile
R. 2020	Nayak et al.	Sustainable reuse of fashion waste as flame-retardant mattress filing with ecofriendly chemicals	Flame-retardant mattress filing
K. 2020	Subramanian et al.	Environmental life cycle assessment of textile bio-recycling – valorizing cotton-polyester textile waste to pet fiber and glucose syrup	Pet fiber and glucose syrup
X. 2020	Zhong et al.	Eco-fabrication of antibacterial nanofibrous membrane with high moisture permeability from wasted wool fabrics	Antibacterial nanofibrous membrane
D.G.K. 2021	Dissanayake et al.	An environmentally friendly sound insulation material from post-industrial textile waste and natural rubber	Sound insulation
M.-P. 2021	Todor et al.	Development of fabric-reinforced polymer matrix composites using bio-based components from post-consumer textile waste	Polymer matrix composites
Z. 2021	Xu et al.	Conversion of cotton textile waste to clean solid fuel via surfactant-assisted hydrothermal carbonization: Mechanisms and combustion behaviors	Solid fuel
M. 2021	Vidaurre-Arbizu et al.	From the leather industry to building sector: Exploration of potential applications of discarded solid wastes	Building sector
X. 2021	Zhong et al.	Highly flexible, transparent film prepared by upcycle of wasted jute fabrics with functional properties	Highly flexible, transparent films
P. 2021	Sadrolodabaee et al.	Characterization of a textile waste nonwoven fabric reinforced cement composite for non-structural building components	Reinforced cement composite
R. 2021	Qi et al.	Clean solid fuel produced from cotton textiles waste through hydrothermal carbonization with FeCl3: Upgrading the fuel quality and combustion characteristics	Solid fuel

Source: The authors.

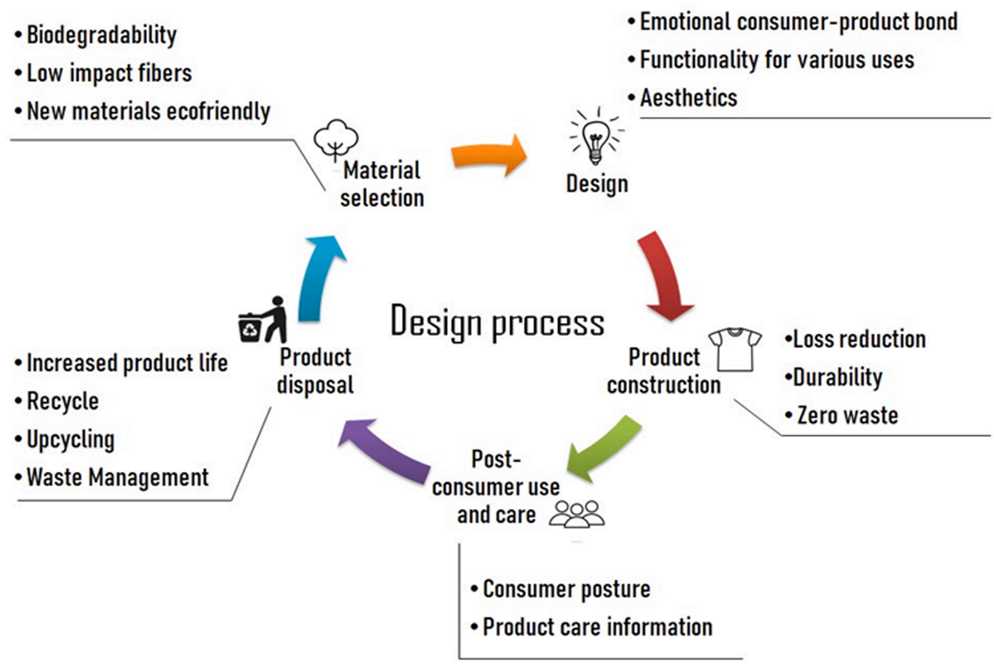

Fig. 3. Product design process based on the circular economy concept. Source: adapted from Elena Salcedo, 2014.

only reduces the volume of waste but also reduces the contamination to the environment (Seguí and Maupoey, 2018; Lee et al., 2019; Ranganathan et al., 2020). Further support in decision-making was suggested by the Commission EU's Member States as a way to monitor the progress of Circular Economy (Teigiserova et al., 2020).

Waste from food industries has great potential as primary or secondary feedstocks for biopolymer production by extraction or fermentation with pre-treatment or without pre-treatment by solid-state fermentation to obtain fermentable sugars. Various types of food waste can be used as substrates for the production of biomaterials (Ranganathan et al., 2020). Thus, the growing demand for environmental sustainability has encouraged research into biodegradable polymers, to minimize the environmental impact of conventional polymers (Balakrishnan et al., 2017; Lee et al., 2019; Tibolla et al., 2014).

Nylon 66 and nylon 6 are synthetic polymers that are widely used in daily life, synthesized by polycondensation of adipic acid and hexamethylenediamine (HMDA) and by ring-opening polymerization of ε-caprolactam, respectively. According to Lee et al. (2019) it is possible to manufacture monomeric precursors of nylon 66 and nylon 6 from food waste, but for that, it is necessary to first extract glucose, 5-hydroxymethylfurfural (HMF) and levulinic acid from food waste (Lee et al., 2019).

Nevertheless, the renewable routes from food waste to the nylon precursors are not yet competitive with petroleum-based processes, principally as the extraction of the starting materials (e.g., glucose, HMF, and levulinic acid) from food waste does not occur on a commercial scale. Instead, petroleum-derived intermediates of the processes could be replaced with renewable ones. This may ease the transition process from current petroleum-based manufacturing (Lee et al., 2019)

In other research, Hu et al. (2017)carried out the production of poly (lactic acid) fibers using fermentative lactic acid from food waste. Poly (lactic acid) was synthesized through ring-opening polymerization, in which the precursor lactide was produced by a novel catalytic method. Under optimal reaction conditions, lactide was produced at yields of 91–92% within 8 h, significantly improving the synthesis efficiency compared to the conventional tin-based catalytic method.

The pure lactide product facilitated the conversion of food waste derived lactic acid to high molecular weight poly(lactic acid) (150,000 g mol−1), which was subsequently spun to fibres with promising tensile and thermal properties for potential applications in textile and bioplastics. As the monomer of PLA, lactic acid (LA) can be derived from renewable biomass resources such as sugar beet and corn (Hu et al., 2017). According to Hildebrandt et al., 2021, fiber PLA can be processed into nonwoven materials in combination with both fossil-based non-biodegradable polymer fibers and natural fibers and/or other bio-based biodegradable polymer fibers.

Other alternative solution, facilitated by the bio-textiles industry, is the introduction of vegan and bio-based leather substitutes for the production of shoes, handbags, clothing's and upholstery i.e. on the basis of natural fibres, bio-based polymers, microbial cellulose and fungal mycelium composite products (Hildebrandt et al., 2021). Hildebrandt et al., 2021 made comparisons between possible biomaterials to replace leather, as can be seen in Fig. 4.

According to authors the major material and energy flows associated with the biofabrication and manufacturing of leather, include the water footprint, the cumulative energy demand for drying, boiling, pressing, and confectioning of the materials, and the upstream material and energy demands for supplementary materials. Hildebrandt et al., 2021 confirm that these alternative leather substitutes contribute to potential long-term strategies for reducing and replacing leather use, but only at a well-balanced mix when upscaling is predicted, and only with the leverage potential for deep impact decoupling. This demands that fast fashion applications do not compromise the attainable impact reductions but instead embrace further impact reduction strategies.

Plant fibers also are among the existing natural fibers, are an attractive material and its features resemble those of synthetic polymers, it could potentially replace its synthetic counterparts (Tibolla et al., 2014). European Union has passed the legislation to use bio fibres as reinforcement during automobile component manufacturing (Sabarinathan et al., 2020). The main reason for using natural fiber as reinforcement is that the energy consumed for the fiber production is less compared with synthetic fiber. The cost associated with the production of natural fiber is less, possibly due to the fact that natural fibres are mostly by-products from the industrial crops (Sabarinathan et al., 2020).

For example, pineapple plants are largely grown in tropical and subtropical countries. In 2018, the global production of pineapples amounted to 27.92 million metric tons. Costa Rica, Philippines and Brazil were the top three pineapple producers worldwide. Its crown it

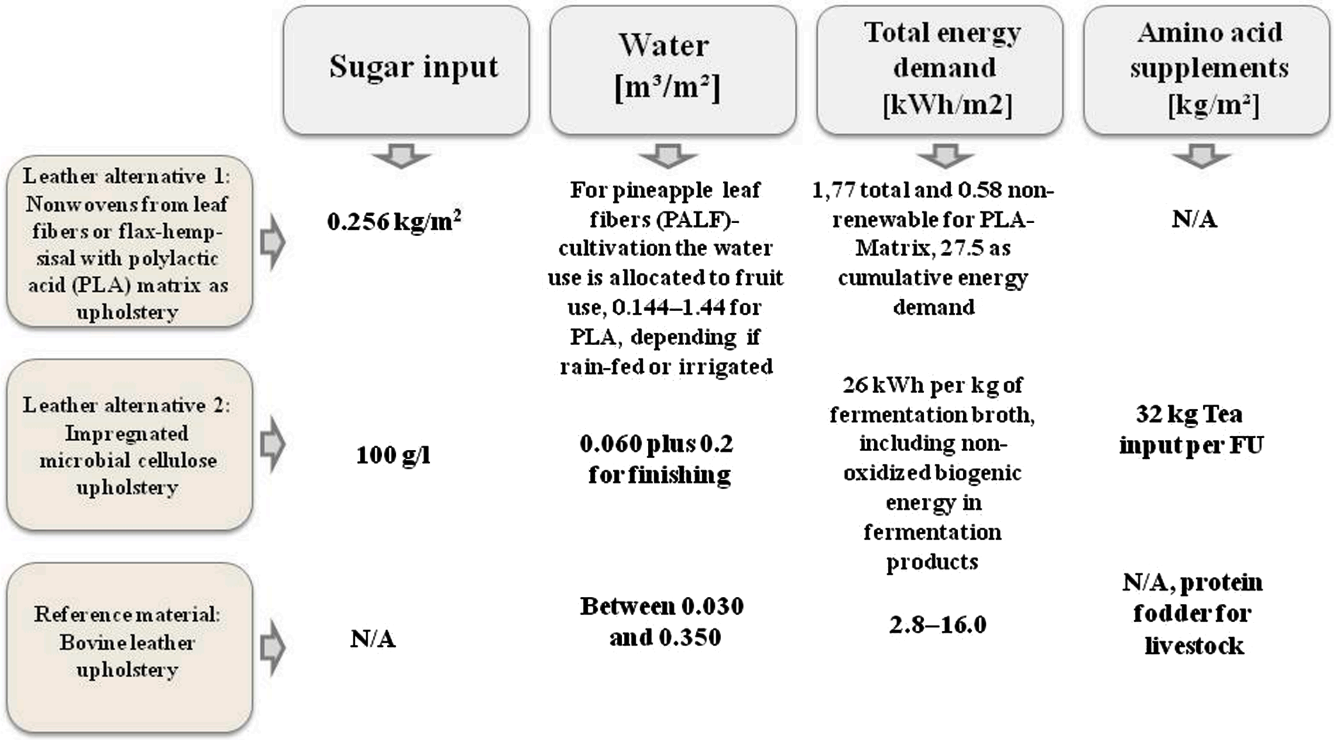

Fig. 4. Comparisons between possible biomaterials for replacing leather. Source: adapted Hildebrandt et al., 2021.

consist of 80% cellulose, however it is considered as a waste material after the harvesting and is usually burned in the middle of the plantation at the end fruit harvest (Balakrishnan et al., 2017; Hazarika et al., 2017; Pereira et al., 2021).

During processing, large quantities of by-products, mainly from bark, peel, and bagasse are generated, which represents about 25–35% of the fruit weight. Therefore, these by-products constitute an abundant and low-cost raw material that could be used as feedstock for biomass conversion processes producing high-value bioproducts such as nanomaterials, which could be used, for example, as reinforcing agent in nanocomposite (Pereira et al., 2021).

In Indian subcontinent, an attempt has been made to extract and soften pineapple leaf fiber by decortication of leaves followed by water retting. The retting time was optimized at 7 days. The retted fibres were then degummed and bleached for better processibility and esthetic look. The degummed and bleached fibres were then successfully converted into textile quality thread of 90 tex through suitable mechanical processing system. Mechanical properties of thread were found to be suitable to make sustainable novelty fabrics for apparel (Hazarika et al., 2017). Pineapple waste, considered an abundant agro-industrial residue, is studied as a low-cost material for the generation of different value-added products (Seguí and Maupoey, 2018).

Food waste can also be a solution for the dyeing, wastewater treatment and energy production sectors. Verma et al., 2021 investigated the effect of biopolymer and dyeing treatment with natural dye (skin of onions) on the functional properties (antibacterial and UV protection) of cotton fabric. The reddish color outer skin of onions was collected from hostel mess where it is discarded as a waste, and cleaned to remove debris and shade dried.

It was found that the chitosan treated onion skin dyed cotton fabric showed 97.20 percent and 98.03% reduction in the growth of E. coli and S. aureus bacteria respectively. The chitosan treated dyed cotton fabric showed the higher ultra-violet protection factor (UPF) value (84.80) as compared to alum treated dyed cotton fabric (66.70) depicting that the chitosan treated dyed cotton fabric provided more ultraviolet protection than the alum treated dyed fabric (Verma et al., 2021).

Orange peel (OP) also is an abundant, cheap and readily available agricultural byproduct. OP extracts can be readily sorbed by wool directly, with aluminum or iron mordants, both of which are benign to the environment and human health. According to Hou et al. (2013), the optimum dyeing conditions included dyeing temperature of 100 °C, dyeing time of 120 min, pH 3 for direct dyeing and pH 7–9 for one-bath mordant dyeing. All the dyed wool fabrics demonstrated good colorfastness to washing with soap, good colorfastness to rubbing and acceptable colorfastness to light. The value of UV-protection Factor (UPF) of the wool fabric dyed with OP extracts using direct dyeing method was about 6 times higher than that of the wool fabric dyed with normal synthetic dyes with similar shade and depth of shade.

Yin et al. (2017) extracted in their research the extract natural colorant anthocyanin from purple sweet potato powder via ultrasound-assisted ammonium sulfate/ethanol aqueous two-phase system. The extracted natural colorant anthocyanin was used to dye silk fabric in a relatively ecological approach. Based on the single-factor extracting experiment, central composite design-response surface methodology was employed to optimize the ultrasound-assisted aqueous two-phase system extracting conditions including ultrasound temperature, ultrasound time and dosage of purple sweet potato powder. This study demonstrated that developed natural colorant extracted from plant could be successfully employed as an effective and eco-friendly alternative cleaner to replace synthetic colorant gradually using in textile dyeing industry.

Regarding wastewater treatment, in Turkey, a hybrid process was applied to pretreated real textile wastewater. Hybrid process included electrocoagulation (EC), adsorption, and photo Fenton- like oxidation methods. Walnutshell and corncob agricultural wastes were used for the preparation of the activated carbon. According to Bener et a., (S. 2020), after adsorption step, the removal efficiency of the total organic carbon (TOC) was found to be nearly 75% and color, turbidity, and total dissolved solids achieved the standards for irrigation water. For researchers agricultural wastes used in preparation of catalysts and adsorbents were promoted to be innovative, environmentally friendly and economical.

Topare and Bokil (2021) also performed tests of adsorption of textile industry effluent using activated carbon prepared from agro-waste materials. They were used green coconut shell and bamboo using ZnCl2 as an activation agent in an adsorption column (fixed bed). The findings demonstrated that both breakthrough and exhaust times increase, with the height of the bed being increased, but decrease with the concentration of the dye inlet. It was observed that the bamboo activated carbon BAC has high carbon content, and has a high potential for dyes removal and may become capable substitutes for costly activated carbon. The adsorption capacities of green coconut shell and bamboo are at par with respect to each other, the overall process scheme may become economical as these materials are available as wastes and practically free of cost.

Finally, the energy efficiency and the development of environmentally correct policies are current topics, especially when applied to the industrial sector with the objective of increasing the competitiveness of the enterprises. One of the existing options for the growth and sustainable development of textile industry is through the use of biomass as an input (Nunes et al., 2015, 2019).

For example, in Greece, the agricultural sector and primarily its cotton subsector are of great importance for Greece, due to the intensive agricultural activities. Thus, according to Zabaniotou and Andreou (2010)the wastes from cotton ginning plants are also considerable and can be valorized for bioenergy production. The substitution of conventional by green fuels, which can be produced from cotton ginning wastes, is a step towards: (a) economic and environmental sustainability for the textile industry and (b) the development of alternative energy supplies, contributing to the reduction of GHG emissions. Furthermore, it consists an especially attractive opportunity to invest in rural areas (Zabaniotou and Andreou, 2010)

3.5. Manufacture of biotextiles using bacterial cellulose for a sustainable fashion industry

With regard to waste management and circular economy, partnerships between sectors can be an excellent solution, since through interdisciplinarity one sector can provide a function for the waste generated in another (Sauvé et al., 2016; Wilkes et al., 2015). An example of this is the waste generated during the production of the probiotic drink kombucha, consisting of bacterial cellulose, which can be used as a potential biomaterial for textiles, footwear and other branches of design (Costa et al., 2019; Yim et al., 2017).

The inclusion of living biological systems in the field of nanotechnology and materials sciences has led to the creation of strategies and solutions through various research lines. This situation has arisen through the efforts of a large number of scholars who are concerned with the development of new sustainable materials that will not be a source of pollution for our planet (Camere and Karana, 2018; Costa et al., 2019).

Biotechnology and biofabrication are related to studies on microorganisms and are considered efficient when compared to other material production technologies, as they do not require the removal of virgin materials from the earth's crust (Camere and Karana, 2018; Scarlat et al., 2015). An example of the use of microorganisms is acetic acid bacteria, mainly from the genus Gluconacetobacter (Costa et al., 2019; García and Prieto, 2019). The cellulosic membrane formed by bacteria is biodegradable (García and Prieto, 2019; Zhu et al., 2016) and this biodegradability is consistent with developing ecologically-friendly products (Freudenreich and Schaltegger, 2020).

Many researchers have also been concerned with low to zero waste projects for the textile industry, especially for activities that involve cutting processes (Chan et al., 2018). It has been demonstrated that bacterial cellulose has a high potential to achieve sustainability through reaching zero waste (Camere and Karana, 2018; Chan et al., 2018). Biomaterials have interesting characteristics in addition to easy degradation, such as the possibility of being cultivated as needed (in various sizes and shapes) (Camere and Karana, 2018; Domskiene et al., 2019). Chan et al. (2018) performed tests using crop containers in the shape of the garment mold, a technique called vacuum molding, since the bacterial cellulose tissue membrane produced from the traditional cultivation container (rectangular or oval) requires additional cutting.

It should be noted that these microorganisms aerobically produce cellulose films that accumulate in the extracellular medium, which can be produced in different thicknesses and, when dry, produce a leather-like material (García and Prieto, 2019; Domskiene et al., 2019). Also, for the manufacture of BC, only small amounts of water and energy are needed (Cazón et al., 2020; Yim et al., 2017). Thus, the use of bacterial cellulose has gained the attention of designers in order to rethink materials, ways of production and contribution to sustainability.

The characteristics of the bacterial cellulose film led to the innovative idea of the cultivation of seamless clothing, due to its direct 3D formation as a leaf (Ng and Wang, 2016; Wang et al., 2015). It should be noted that the synthesis of BC can be conducted under static or dynamic conditions, resulting in different forms of cellulose, that is, three-dimensional interconnected reticular films and irregularly shaped, ball-like cellulose particles, respectively (Chan et al., 2018; Costa et al., 2019; Kamiński et al., 2020).

One way to obtain bacterial cellulose is from the production of the probiotic drink known as kombucha, this being considered a sustainable source for the manufacture of BC films (Filippis et al., 2018; García and Prieto, 2019; Costa et al., 2019; Kamiński et al., 2020). Suzanne Lee, founder of Biocouture, is a fashion designer and pioneer in the technique of using bacterial cellulose obtained through kombucha fermentation (https://www.launch.org/innovators/suzanne-lee) (Chan et al., 2018; Kamiński et al., 2020).

Although research on BC is growing rapidly, there are still many technical and practical problems associated with making clothes that need to be solved (Kamiński et al., 2020). Mechanical durability, comfort, material contamination, organic acids (responsible for the characteristic unpleasant smell), attack from microorganisms (Kamiński et al., 2020) and how to adapt these materials to the production of products on a large commercial scale (He et al., 2020; Domskiene et al., 2019) are some questions raised by researchers. Studies on alkaline treatment have been conducted, but the alkaline purification method requires the use of significant amounts of water and neutralizers to obtain materials with neutral pH (Cacicedo et al., 2016; Kamiński et al., 2020).

3.5.1. Economic aspects of biotechnology manufacturing

The success of building an economically viable bioprocessing method is strongly dependent on reducing the cost of the substrates, increasing the yield of the product and increasing the production rate (Reiniati et al., 2017). The high cost of culture media for the production of BC in the laboratory led some researchers to propose alternative strategies to overcome this disadvantage, aimed at industrial production (Islam et al., 2017; Machado et al., 2018).

Designs have been proposed for advanced reactors, like the rotary disk reactor, as well as additives that increase the production of bacterial cellulose, such as carboxymethylcellulose and organic acids (Ul-Islam et al., 2020). However, with regard to large-scale production, strategies involving cheap raw materials and carbon sources need to be proposed (Islam et al., 2017).

According to Barshan et al. (2019), considerable effort has been focused on finding new low-cost carbon sources. The use of vinasse, for example, is a promising practice as it increases productivity and reduces the costs and volume of effluent generated. Revin et al. (2018) observed the accumulation of a large amount of bacterial cellulose (6.19 g/L) in fine wheat vinasse after 3 days of cultivation under dynamic conditions, almost three times greater than in the standard Hestrin and Schramm medium (2.14 g/L).

The possibility of using cheap raw materials as substrates makes the production of bacterial cellulose more attractive and viable, and potential candidates would be agricultural and industrial food residues, including saccharified food residues, grape medium, pineapple juice, grape marc, glycerol from biodiesel and low quality syrup (Reiniati et al., 2017). It should be noted that the use of residues or by-products from agroforestry and the food industry as sources of carbon and nitrogen for new compositions of culture media, in addition to reducing the cost of production, allows the high quality of the BC produced to be maintained (Machado et al., 2018).

In this context, the production of bacterial cellulose through the production of the probiotic drink kombucha is an attractive option in relation to costs. As noted earlier, the main raw material used to make the drink is green tea (*Camellia sinensis*), which can be sweetened with organic products, such as sugar cane molasses or sugar for domestic use (Machado et al., 2018; Song and Kim, 2019).

According to Hildebrandt et al., 2021 market oversaturation of kombucha tea can lead to decreasing kombucha tea prices, thereby influencing the allocation by price as a higher share of revenues will be from alternative leather sales. To increase the circularity within microbial cellulose production, the use of waste substrates, e.g., from secondary brewing of waste substrates from tea brewing and instant tea production in the beverage industry or pasteurized fruit waste from fruit jelly production, could allow for a circular supply chain strategy. Furthermore, integrating starch producing companies, such as potato starch production, with enzymatic saccharification combined with a later integration into existing wastewater infrastructures should be considered.

3.6. The sustainable development goals and the circular economy

The concept of circular economy has the potential to contribute to several UN Sustainable Development Goals (SDGs) (Durán-Romero et al., 2020; Centobelli et al., 2020). According to Kristoffersen et al. (2020), in relation to CE, eliminating or reducing structural waste decreases the demand for virgin finite material as well as the contamination of the natural environment through the dumping of used resources. Therefore, CE practices are strongly linked to SDG 12 (responsible consumption and production), SDG 6 (clean water and sanitation), SDG 7 (clean and accessible energy), SDG 13 (climate change) and SDG 15 (life on earth) (Durán-Romero et al., 2020; Centobelli et al., 2020; Chen et al., 2020; Kristoffersen et al., 2020; Schöggl et al., 2020).

Currently, 40% of the world's population is seriously negatively impacted by water scarcity and pollution, due to both the presence of toxic industrial chemicals and global warming (Chen et al., 2020). Therefore, cleaner production practices need to be adopted, prioritizing those which are consistent with a circular economy and contribute to the SDGs (Durán-Romero et al., 2020; Centobelli et al., 2020). Fig. 2 shows the relationship between the circular economy and the SDGs, promoting a more sustainable society through a circular system.

Therefore, in the case of production processes and industries, SDG 12 has been the most targeted goal as a starting point for the implementation of the CE concept (Giannetti et al., 2020; Schöggl et al., 2020). SDG 12 is composed of 11 targets, which aim to implement the Ten-Year Plan of Programs on Sustainable Production and Consumption, addressing, for instance, how to correctly manage waste and rationalize inefficient fossil fuel subsidies (UNDP, 2015).

According to Corrado et al. (2020), in a globalized economy, where raw materials and semi-finished and finished products are widely traded, the growing demand for products in developed countries generates considerable pressures on the environment and causes serious impacts. Therefore, life cycle assessment and environmental impact due to the production and consumption of goods and services is a crucial step towards achieving sustainable development goals (SDGs) (Corrado et al., 2020; Sala and Castellani, 2019).

One of the ways to mitigate negative environmental impacts is the adoption of cleaner production (CP) practices and this is in line with SDG 12. These practices contribute to the preservation of raw materials and energy, reducing or eliminating the emission of toxins and waste during production processes. Thus, the implementation of CP practices should be a priority in the textile, clothing and leather industries (Neto et al., 2019).

In China, a monitoring framework for the implementation of the CE concept (macro level) has been developed, based on a Chinese statistical system and previous research linked to economy material flow accounts (EW-MFA). For this monitoring, indicators were used, such as the pattern of consumption and use of material per capita (SDG 12.2) along with the production, circularity, recycling rate and total waste throughout the life cycle and amount of waste sent to landfill (SDG 12.5) (H. Wang et al., 2020).

The European Commission (EC) has pledged to fully integrate the SDGs into the EU policy framework and EU priorities, assessing the current status and identifying the most relevant sustainability concerns

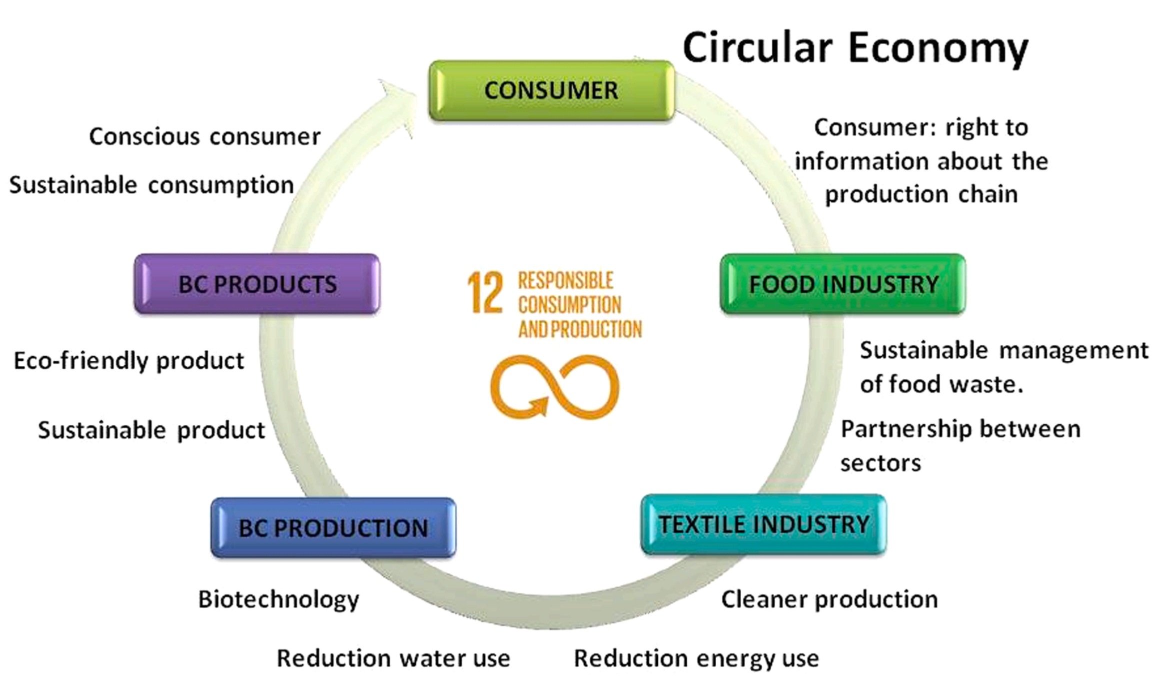

Fig. 5. Possible relationship between the textile industry, food industry and the ODS 12. Source: the authors.

(Corrado et al., 2020). Waste prevention, for instance, is considered a priority under the European waste policy. Reducing food waste has recently been recognized as a priority area at the international and European levels and in Norway (Sadeleer et al., 2020). Thus, the aim is to reach target 12.3, which aims to "halve per capita global food waste at the retail and consumer levels and to reduce food losses along the production and supply chains, including post-harvest losses" (UNDP, 2015).

Lastly, a consideration of the interdisciplinarity between the food sectors through the use of bacterial cellulose in the textile and fashion industries for the manufacture of biotechnologies, should include target 12.5, which aims to substantially reduce the generation of waste through prevention, reduction, recycling and reuse, and target 12.c, which seeks incentives to rationalize inefficient fossil fuel subsidies and minimize negative environmental impacts (UNDP, 2015). Fig. 5 shows the possible relationship between the textile industry, food industry and the ODS 12 thinking of a Circular Economy.

Fig. 5 illustrates the possibility of thinking about a Circular Economy between the food and textile sectors through the production of a biotextile. As well as the importance of adhering to the Sustainable Development Goals, in this case, SDG 12 and including its waste management goals, cleaner production, and ensuring that people everywhere have the relevant information and awareness for the sustainable development and lifestyles in harmony with nature.

5. Final considerations, trends and future research

The aim of this study was to review and shed light on the current state of research on the circular economy concept, relating it to the food and textile industries, in order to propose a dialog between the two sectors regarding the reuse of waste. Theoretical studies on the concepts of CE, CE in the food industry and CE in the textile, clothing industry were discussed and examples of research that addressed the reuse of food waste for the production of biopolymers were discussed.

Subsequently, the applicability of the CE concept to the food and textile sectors was analyzed, using as an example the reuse of bacterial cellulose waste from the production of the drink kombucha in the development of biotechnologies for the textile industry. It should be noted that this action is consistent with a circular economic system and favors the achievement of UN Sustainable Development Goals, such as SDG 15, SDG 13, SDG 7, SDG 6 and, especially, SDG 12.

Through this study, the real possibility of making new textiles and revaluing millennial natural fibers from plant residues such as pineapple was observed, but also about the limitations and difficulties, mainly thinking about replacing products from limited natural resources such as oil. Therefore, it was demonstrated the importance of future theoretical and practical studies on the reuse of waste from one sector to another, through interdisciplinarity. As well as further studies on energy and water savings, production yields, among other challenges.

In this regard, the use of bacterial cellulose in clothing production can be highlighted as a good example, offering ecofriendly characteristics. In future research, the limitations associated with large-scale commercial production also need to be addressed for the utilization in fashion industry.

Author statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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