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SUMMARY

Sustainability in all its dimensions – in particular environmental sustainability – is currently attracting a tremendous amount of attention worldwide. The necessity of packaging is sometimes the subject of severe debates, and in the face of ongoing environmental problems, it is still having a difficult time despite the usefulness of its functions. Accordingly, packaging optimisation and reduction, but currently also the substitution of materials and recycling management, are still on the agenda; enormous innovation pressure is being exerted on the companies producing and using packaging, urging them to take sustainable and future-oriented action.

This article begins by focusing on the necessity of packaging, its functions and properties, and on criteria for sustainability. This is followed by a more in-depth look at bioplastics. The authors highlight the differences between bio-based and biodegradable plastics, giving examples and presenting the application of these materials in food packaging. Finally, the article focuses on sustainability aspects of bioplastics. A clear distinction between bio-based and non-degradable, bio-based and biodegradable as well as petro-based and biodegradable plastics is essential. There must be clear communication and clarification in this respect, as the term “bioplastics” is not used in a clearly defined manner.

INTRODUCTION

According to the Food and Agriculture Organisation of the United Nations (FAO), up to one-third of food produced for human consumption is lost or wasted along the supply chain every year. This equals an enormous volume of approximately 1.3 billion tonnes. The term “food loss” refers to the reduction of food between its primary production and being bought/sold: during harvesting, processing, storage, packaging and transport. A common example is fruit and vegetables that are damaged during transport due to inadequate packaging. “Food waste” on the other hand refers to the disposal or alternative use of food. Examples in this respect are products that are rejected due to their non-standard size, shape or colour, redundant food in households and group catering, and products disposed of shortly before or on the best-before date – and still fit for consumption [1, 2].

While food loss is particularly challenging in countries with low average incomes, food waste is a clear focus in countries with high average incomes [2]. The task of quantifying this situation often proves difficult [3]. For example, a study carried out in Europe (EU-28) showed that about 20 % of food (173 kg per person per year) is lost or wasted. For the most part, this occurs at the end of the supply chain (consumption), namely in the household sector (53 %) and the food service sector (12 %). In the upstream stages of distribution (wholesale and retail), processing and production, however, 5 %, 19 % and 11 % of waste occurred [4].

Figuratively speaking, the immense amount of food not consumed can be seen as the tip of an iceberg. It conceals the enormous waste of valuable resources such as water, land and energy, but also of labour and capital. In addition, unnecessarily produced greenhouse gas emissions contribute to global warming and climate change. Last but not least, we are seeing how the situation of food insecurity, already fraught by the steadily growing world population, is growing worse [1, 2]. Accordingly, the environmental impacts of packaging often account for only a small percentage of the filling goods [5, 6].

Against this background, it seems more than justified that governmental and non-governmental organisations on the national and international level have been advocating the reduction of food loss and waste for a number of years now [1, 7, 8, 9]. Similar to the waste hierarchy (EU Waste Directive 2008/98/EC), which covers the avoidance of waste, preparation for re-use, recycling or other recovery (e. g. energy recovery) and finally disposal, the discourse on food loss and food waste focuses primarily on the avoidance of food loss and food waste. This is followed by the redistribution of food (e. g. passing food on to charitable institutions), its use as animal feed, composting and the production and disposal of renewable energy [7, 10]. In order to actually achieve a reduction in loss and waste, it is essential that we identify the associated quantities and causes and analyse the latter at the micro, meso and macro levels. We will then be able to develop customised solutions accordingly [10].

One very important cause, but also a solution, is often the packaging. While a lack of packaging, or packaging incorrectly chosen and used, can cause food loss and food waste, packaging that is adapted to the product and its lifecycle can be the solution. The possibilities offered by modern packaging, such as "active" and "intelligent" packaging, are also interesting in this context. One example for active packaging is oxygen absorbers; for intelligent packaging, materials that act as time-temperature indicators [10].

While this approach justifies the necessity and use of packaging, packaging today also poses an environmental problem and is the subject of heated debate. Current developments and general conditions are therefore exerting a great deal of innovation pressure on companies producing and using packaging, calling for sustainable and future-oriented action. In addition to the reduced use of packaging, the current debate focuses on the recyclability and substitution of plastics (e. g. paper) and bioplastics [11, 12, 13].

Bioplastics in particular constitute an ambiguous topic for many users/companies. This article therefore aims to convey basic knowledge in the field of packaging and sustainability and in particular address bioplastics and their usefulness and suitability for application in the food sector.

PACKAGING: FUNCTIONS AND MATERIAL PROPERTIES

Functions

Packaging mirrors society. It is indispensable in many areas for protecting goods, especially food, from loss of quality along the supply chain. In other words, it does not fulfil an end in itself. The type and design of the selected type of packaging is inextricably linked to the respective product properties and requirements. As diverse as the types of packaging available on the market may be, they still have a common denominator in their functions. Only if the packaging types are carefully selected and adjusted can a product packaging system be successful and continue to exist (see Figure 1) [14, 15, 16].

A function often not noticed, but one that is fundamental, is the storage of food. With the exception of a few chunky, relatively large products, it is usually necessary to prevent product loss and/or contamination and thus make **storage**, transport and distribution possible in the first place. An example product with relatively strict requirements for this function is liquid food; an example for low requirements is fresh produce – fruit and vegetables [16, 17].

The **protective function** can be regarded the most important role of packaging. It reduces or prevents extrinsic but also intrinsic physical, chemical and biological factors that have a negative influence on the quality of food. Ideally, this enhances the shelf life of the products. A loss of integrity in the packaging, on the other hand, can have the opposite effect. In the process of selecting packaging, it is therefore particularly important to consider a product's properties and requirements in detail. Examples of foods with strict requirements for the protective function of packaging are fresh foods such as milk and meat, fragile products such as eggs, but also oxidation-sensitive products such as oils. Dry products such as salt or pasta, on the other hand, have low requirements [16, 17].

Convenience, i.e. the user-friendliness or practical suitability of packaging, often determines the success of a product on the market and is increasingly geared towards the needs of the respective target groups. These include, for example, easy-to-open and resealable packaging, individually packaged portions or "frustration-free" packaging [16, 17].

Communication is another complex packaging function that essentially comprises information and marketing. This includes a constantly increasing amount of information required (by law, regulations), necessary information (e. g. barcodes) and voluntary information (certificates, instructions), but also product and brand recognition. For the latter point, there are many examples where the unmistakable design of the packaging has the same or even greater recognition value than the product name [16, 17].

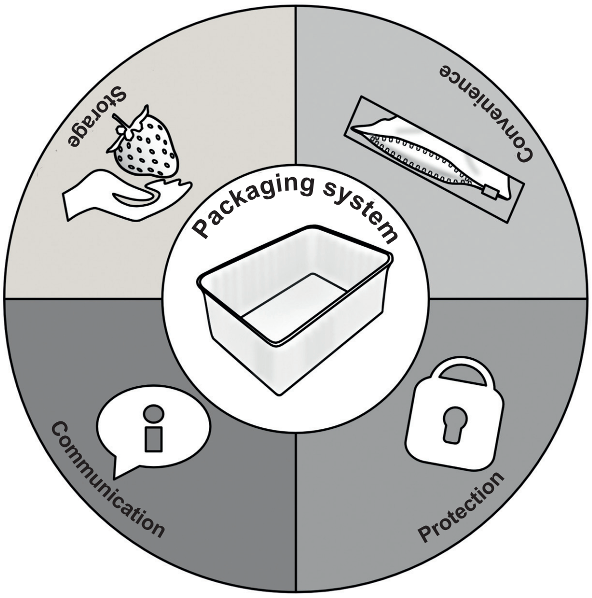

Figure 1: Packaging functions (graphic created based on [18])

Properties

A key decision in developing specific packaging is often the selection of materials (packaging materials) according to their properties (see Figure 2). In general, it can be said that every packaging material, whether glass, metal, plastic, paper/ carton/ cardboard, but also composite materials (e. g. plastic-coated carton), has advantages and disadvantages in various requirements/ properties (see Table 1, page 6). Accordingly, in the overall context of food, packaging and the supply chain, it is necessary to decide which material should be preferred. While the properties of certain types of packaging, or their components, are sometimes recorded in specifications and declarations of conformity, it is advisable also to test the properties under application conditions to ensure that any deviations are detected early on in the development process [16, 17, 18]. Some of the most important properties are listed below.

During its lifecycle, packaging can be exposed to considerable **physical and mechanical stress**. This can be due to the manufacturing process and the subsequent interaction between the packaging and the contents, but also to the packaging process, storage or transport. Static stress (permanent and slow-acting) occurs, for example, during stacking, the formation of negative pressure in the packaging due to vacuum packaging, hot filling or modified atmosphere, but also in the case of edged products. Dynamic stress, on the other hand, can occur during the finishing process of the packaging (e. g. printing, forming), caused by the product or the process during packaging, or caused by vibration and impact during transport. The properties can be determined or inspected by means of field tests (e. g. transport and storage tests), but also by laboratory tests (e. g. compression test, drop test, puncture resistance) [16, 17, 18].

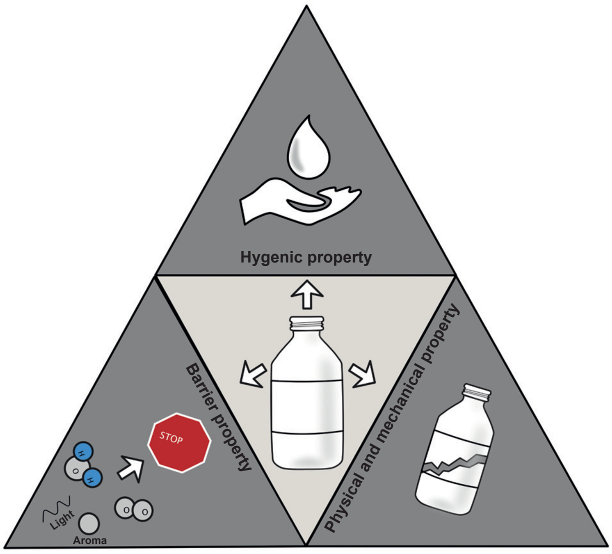

Figure 2: Properties of packaging materials
(graphic created based on [18])

In addition to the physical and mechanical properties, the storage and protective function of packaging is largely determined by the **barrier properties** of the packaging material selected. In this context, we must emphasise the barrier against oxygen and water vapour in particular, as this can have a strong influence on the shelf life of food in terms of quality, declaration and safety. While oxygen can promote oxidation, loss of quality-relevant constituents and the growth of microorganisms, water vapour is a major contributor to structural changes and to loss or uptake of water in products. In addition, it may also promote microbial growth. Apart from the two gases mentioned above, in many cases the barrier against carbon dioxide, nitrogen or aromatic substances may also be of interest.

With regard to the barrier, it is essential that the packaging should be sufficiently impermeable to prevent any unwanted diffusion of gases and thus the exchange of atmosphere inside and outside the packaging. Only then can the gas permeability (permeation) of different plastics, for example, and their effect on the shelf life of food be taken into account, which is often the decisive point in favour of or against a particular material. The impermeability of packaging, but also the permeation, can be checked in the laboratory [17, 18, 19].

Another barrier function that packaging can offer is shielding the product from the effects of light, which can accelerate oxidative and other chemical reactions (e. g. formation of the "off" flavour in milk) and thus also result in the loss of quality-relevant ingredients. In addition, light can cause structural damage to the product. Depending on the material selected, its colouring, printing or use in combination, its pigmentation but also metallisation, it is possible to ensure higher or lower light transmission [17, 18, 19, 20, 21, 22].

Migration is described as the mass transfer from a packaging material into the product (food). The driving force in this process is a concentration gradient. Depending on factors such as the properties of the material, the process conditions, the product, the migrating substance and the storage conditions (especially temperature and time), a high or low level of migration can occur and thus result in a possible health and safety risk. Contrary to wide-

Table 1: Overview of advantages and disadvantages of packaging made of plastic, metal, glass and paper/cardboard (table created based on [18])

Packaging material	Advantages	Disadvantages
Plastic	· Lightweight material (low density) · Excellent formability · Low cost · Versatile, controllable properties (physical and mechanical properties, chemical resistance, temperature resistance, barrier) · High convenience (e. g. good transportability, lightness, break resistance) · Non-conductor · Can be used in combination with other materials	· Low temperature resistance · Stability · Migration potential · Expensive separation and sorting · Recycling implemented so far only for some plastics · Unfavourable image
Metal (aluminium, tinplate)	· Excellent barrier properties · High mechanical stability · Temperature stability · Good formability · Recyclability	· Energy-intensive production · Heavy material (high density) · Not transparent · Not thermally usable · Not reusable · Often difficult to empty completely · Not suitable for microwave ovens
Glass	· Excellent barrier properties · Chemically resistant material · Hot filling and heat treatment possible · Hygienic, washable and sterilisable · Different shapes possible · High mechanical stability, rigidity · Pressure resistant · Reusability and recyclability · Available transparent and in colour · Can be disposable or reusable · Suitable for microwave ovens · Positive image	· Energy-intensive production · Heavy material (high density) · High logistics costs · Risk of breakage · No flexibility
Paper/ cardboard	· Good mechanical stability · Renewable · Recyclable · Thermally usable · Can be used in combination with plastic	· Not transparent · Poor barrier properties · Very limited use for pasty/liquid foods

spread perception, migration is found not only in plastics, but also in other packaging materials and can be caused not only by the packaging material but also by packaging aids (e. g. labels) or the invisible set-off of the outside on the inside of the packaging when pre-produced packaging materials are stacked/wound, or by the storage conditions of the finished product. The migration can be checked for the respective product packaging system and the intended use in the laboratory – based on specifications of the European Union [18, 23]. It is also interesting to note that, in addition to migration into the product, substances may also migrate from the product into the packaging material (sorption or scalping). This type of migration can sometimes result in product influences (e. g. loss of flavour) and adversely affect the reusability of reusable containers due to the later re-release of the migrated substances [24].

Last but not least, the **hygiene** of packaging materials is relevant: depending on their type and composition, they constitute a barrier against contamination, microorganisms and food pests. The prerequisites for the effectiveness of the barrier are impermeability and freedom from contamination of the materials used. It is also important to recognise that the materials may encourage microbial growth. Most packaging materials are exposed to high temperatures during their production and therefore initially show no or only minor microbial contamination. The main challenge with these materials is therefore to avoid recontamination during storage, refinement, application, etc. Depending on the hygiene requirements, the packaging process involves selecting different materials and, if necessary, taking germ reduction measures [18, 25].

SUSTAINABILITY AND PACKAGING

Although the previous sections show that packaging has many advantages, the general public today still often perceives it as something negative [6]. This is based on the fact that the consuming target groups usually do not recognise the role of packaging, therefore considering it a necessary evil or an unnecessary cost factor. They also see packaging as increasingly pointless, a serious waste of resources and a threat to the environment. One explanation for this attitude towards packaging is that, on the one hand, the functions of packaging are often unknown or unrecognised, i.e. there is a lack of information; on the other hand, the moment of interaction with packaging lies at the end of the supply chain, where packaging has already fulfilled its functions and is usually considered waste [16].

In light of these factors as well as current global developments and general conditions, the call for sustainable packaging – and thus innovation pressure exerted on packaging-producing and packaging-marketing companies to act in a sustainable and future-oriented manner – is intensifying dramatically. But what actually constitutes sustainable packaging? Is it possible to define the one sustainable type of packaging? While we can already partly answer the first question (see sustainable packaging criteria) and pursue different approaches, the second question has to be answered “No”, as several factors (e. g. product, supply chain, trade requirements) and dimensions (ecological, economic, social) have to be taken into account [6, 26, 27, 28].

There is no doubt that the development of sustainable packaging requires time and investment. On the other hand, however, we find advantages in the various dimensions of sustainability. Examples include cost reduction, reduced environmental impact, improved perception by target groups and the decision-making process. In addition, it is possible to increase the positive influence in the packaging chain and the corporate world.

On the road to sustainable packaging, it will be essential to establish lifecycle thinking and a closed-loop economy and to use lifecycle analysis in the development process and along the product lifecycle as a basis for decision-making. In addition, it is

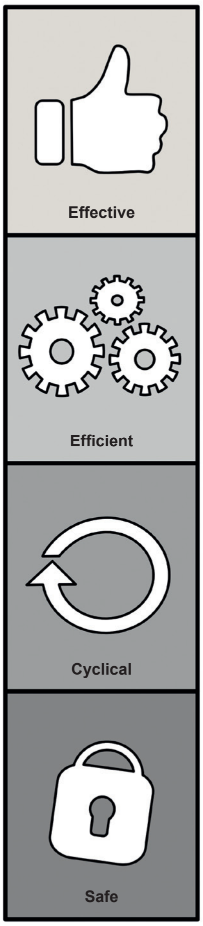

Figure 3: The four key elements of sustainable packaging (graphic created based on [7, 34])

important that an appropriate strategic corporate approach should form the basis for the desired developments [6].

SUSTAINABLE PACKAGING CRITERIA

In recent years, various sustainability criteria have been developed for packaging [6, 26, 29]. The “Packaging Sustainability Framework” (see Figure 3, page 9) provides a condensed yet comprehensive approach to the key issues. This framework uses a total of four principles, described below, to make decisions regarding the design, manufacture, transport, use and end of life of packaging. It should be emphasised that the principles or key elements of the framework are interlinked and that changes in one area can therefore have a positive or negative impact on other areas. Thus, it is only through fine-tuning that we will achieve a balanced, sustainable packaging solution that offers environmental, economic and social benefits [6, 30].

In order to contribute to sustainability, packaging must first and foremost be **effective**, i.e. usable. In general, this means fulfilling the packaging functions (storage, protection, convenience, communication) (see above) [6].

To be **efficient**, packaging must be designed according to the minimum principle. The aim is to minimise the consumption of resources (e. g. materials, energy, water), waste and emissions along the lifecycle. It is important to ensure that the optimum amount of packaging is used and that overpackaging is avoided. If too little or inadequate packaging is used, the negative environmental impact increases exponentially due to possible product losses and waste as well as the packaging used unnecessarily. If too much packaging is used, the environmental impact increases linearly due to the excessive packaging [6, 31].

Another goal is to achieve circular packaging. To do so, it will be necessary to close cycles and maximise the recovery of materials, energy and water throughout the lifecycle. This can include, for example, renewable materials and energy, design for reuse or recycling, and the use of recycled materials [6].

Last but not least, it will be necessary and indispensable to design packaging in such a way that it is **safe**, i.e. environmentally friendly and free of harmful substances, and thus does not endanger either people or the environment. This includes avoiding hazardous substances, utilising environmentally-friendly production, taking responsibility for the environment and reducing waste [6].

BIOPLASTICS

In today's environmental and packaging discourse, bioplastics are repeatedly being presented as a solution to the challenges of packaging, their popularity due to the general efforts towards sustainable development. However, the innovative power they generate also poses a challenge for users and target groups in many respects. Frequently asked questions usually revolve around the definition of bioplastics, the possible areas of application, the material properties and recycling options as well as recyclability. These questions will be dealt with briefly below.

DEFINITION OF (BIO)PLASTICS

Plastics (polymers) are macromolecular compounds composed of recurring basic units (monomers). These components are mainly based on carbon and hydrogen. Minor amounts of oxygen and nitrogen may also be present. Depending on which monomers the polymer is based on, how they are crosslinked or branched and the dimensions of the molecules created from them, it is possible to create materials with a wide variety of properties. In general, plastics can be roughly divided into thermoplastics (non-crosslinked polymers), elastomers (wide-meshed crosslinked polymers) and duromers (close-meshed crosslinked polymers). In contrast to the other two groups, thermoplastics offer the possibility of being repeatedly moulded into different shapes by heating. This was decisive for their triumphant entry into packaging applications [16, 32].

Conventional plastics, based on fossil raw materials such as crude oil and natural gas, are not degradable. The most widely-used plastics in terms of volume in the packaging industry are polyolefins [polyethylene (PE) and polypropylene (PP)], polyethylene terephthalate (PET) and polystyrene (PS). In addition, some other plastics such as polyamides (PA) are used in small quantities [33].

It is interesting to note that in the early days of plastics production only bio-based plastics were produced (e. g. cellulose acetate, linoleum, rubber). It was only after the end of World War II that fossil raw materials experienced their upswing with the increased production of oil [34].

The term **bioplastics** describes a large family of materials with different properties. Since a uniform international definition is not yet available, these are usually described as materials that are either bio-based, biodegradable or both (see Figure 4).

Plastics that contain regenerative, bio-based molecules as building blocks (monomers or polymers) and build on them in whole or in part are regarded bio-based and non-biodegradable. In established synthesis processes, they are used to produce plastics that have the same chemical compositions and thus the same properties and applications as petrochemical products (e. g. bio-PET). These "drop-in" solutions thus make it possible to utilise existing possibilities for production, collection and recycling. As a result, these plastics currently constitute the largest group of biopolymers in absolute terms and also have a very high growth potential. In the food sector, plastics of this group can be found in applications such as films, bags, cups, tubes and bottles.

Biodegradable plastics, on the other hand, can be produced from both renewable and petro-based raw materials. It is essential that the chemical composition of the molecules should permit degradation. Depending on the environmental conditions where this is possible, we speak of "degradable", "biodegradable" or "compostable" plastics. Examples of bio-based and biodegradable plastics are (thermoplastic) starch and polylactic acid (PLA). An example of a petro-based and biodegradable plastic is polybutyrate adipate terephthalate (PBAT). In the food sector, these plastics are mainly used as packaging, bags, filling material or disposable articles (e. g. cups, cutlery) [16, 17, 35, 36].

Although the absolute quantities of bioplastics compared to conventional plastics are still used in manageable amounts, it is a rapidly growing market [33, 36, 37]. Providing an overview of the plastics on this market, the following is a description of a few selected examples.

BIO-BASED PLASTICS

Bio-based and non-biodegradable

Bio-polyolefins [bio-polyethylene (PE) and bio-polypropylene (PP)] are based on renewable raw materials such as sugar cane. This material is used to produce ethanol, which is processed into ethylene in several steps. Bio-PE or bio-PP is then produced by polymerisation. The properties and applications are the same as for conventional PE and PP. We can only differentiate between the plastics by using the radiocarbon method. Application examples in the food industry include films, bags, hollow bodies (e. g. bottles) and carton composites [34, 38, 39].

The molecules monoethylene glycol (MEG) and terephthalic acid form the basis of PET. While MEG can already be obtained from renewable raw materials (bioethanol), thus making **bio-polyethylene terephthalate (Bio-PET)** 30% bio-based, there is presently still no cost-effective way to produce terephthalic acid that is bio-based. If we succeed in closing this gap in the future, bio-PET will also be 100% bio-based. Due to its properties, bio-PET is used like conventional PET in various food and beverage packaging applications [34, 39].

At present, various performance plastics can be produced bio-based. For (food) packaging, however, **bio-polyamide (bio-PA)** is of particular importance. The raw material source for this is usually castor oil. PA (known in everyday life as nylon) is valued for its tear resistance, elasticity and good barrier properties [38].

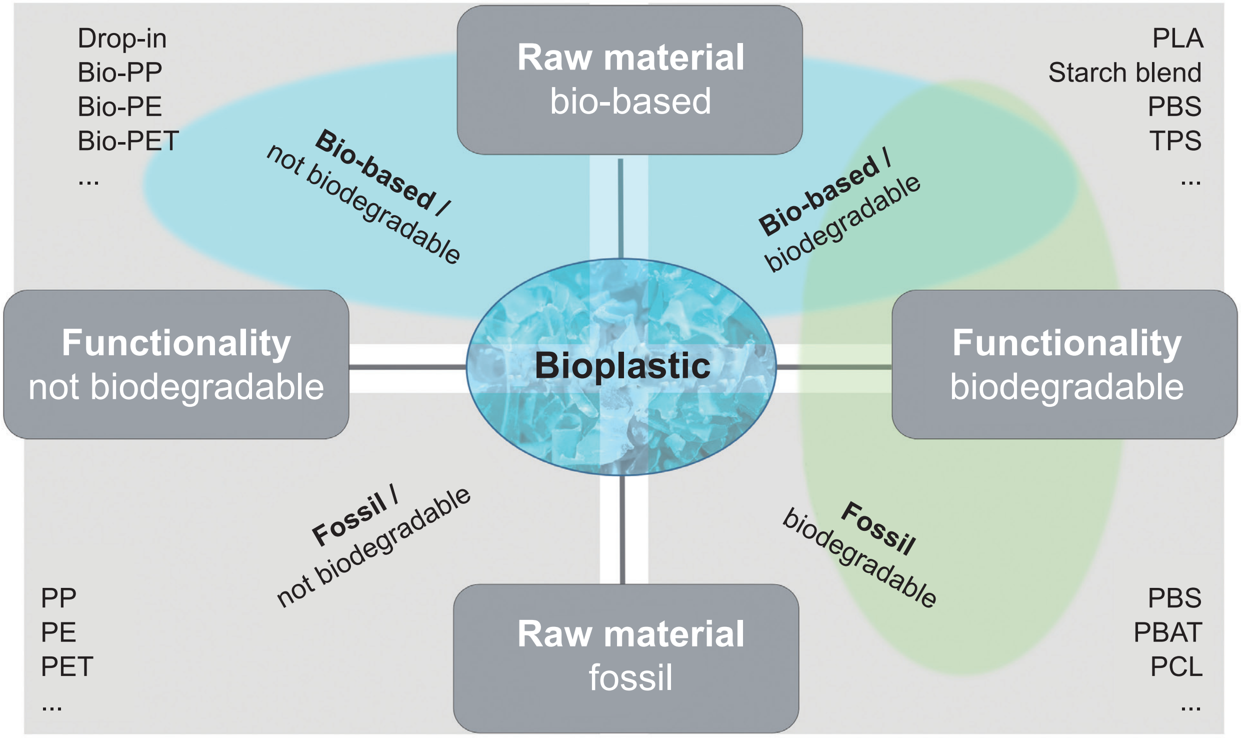

Figure 4: Classification of (bio)plastics (graphic created based on [40])

A bio-based material similar to PET is **polyethylene furanoate (PEF)**. Compared to PET, PEF can be produced entirely from plant raw materials (e. g. waste products) and even exceeds PET in some properties (strength, barrier, processing). At present, the plastic is still in the development phase, but has high future potential, not least due to the potential for recycling it together with PET [40].

Inspection and labelling of bio-based plastics

As a rule, the external appearance of a plastic does not allow us to draw any conclusions as to whether it is a bio-based plastic or not. For this reason, the standards DIN EN 16640 and DIN EN 16785 (part 1 and 2) were developed in the past. They make it possible to determine the content of bio-based carbon or bio-based material. In addition, they form a harmonised framework for declaration and certification (e. g. TÜV “OK bio-based”, “DIN-tested bio-based”) and provide the basis for transparent communication. However, it should be emphasised that the bio-based content of a material does not allow us to draw any conclusions as to its sustainability. To be able to assess the respective environmental impacts, it is always necessary that we conduct a detailed lifecycle analysis.

BIODEGRADABLE PLASTICS

Bio-based and biodegradable

Thermoplastic starch (TPS) is a biopolymer which has starch (e. g. from maize, wheat, potato) as its source material. Chemical modification and the admixture of additives such as water and plasticisers (e. g. glycerine) produce an extrudable material that is easy to process. Since TPS tends to absorb water, plastic blends (mixtures with other plastics) are usually used to obtain improved properties. However, this can also lead to a change in the degradation behaviour. Example applications are bags, cups and disposable dishes as well as coatings for paper and cardboard [32, 34, 39, 41].

Polylactic acid (PLA) is based on the fermentation of sugar into lactic acid and the subsequent polymerisation. At the end of the multi-stage process is a plastic with high transparency and mechanical strength that can be processed by means of conventional methods (injection moulding, extrusion, thermoforming). Depending on the mixing ratio of the stereoisomers of the lactic acid [poly-D-lactide (PDLA) and poly-L-lactide (PLLA)], this results in different property profiles. Since the fermentation process primarily produces L-lactic acid, PLA for packaging applications usually consists of PLLA with an admixture of PDLA in the low percentage range. While the material that results usually provides a poor water barrier, it offers a good oxygen barrier and can thus be used for bottles, trays, films and other containers. Like TPS, PLA is also easily degradable and is often used in blends [32, 34].

Like PLA, **polyhydroxyalkanoates (PHA)** are biogenic polyesters. These are storage and reserve substances of bacteria, produced by fermentation. The most important representatives of this group are polyhydroxybutyric acid (PHB) and polyhydroxybutyrate valerate (PHBV). What they have in common is the fact that they are easy to process (extrusion, injection moulding) and they are degradable. Their resistance to water and grease and their barrier properties in terms of gases are likewise excellent and, in some respects, exceed those of other biodegradable plastics (such as PLA). At present, however, the low availability and relatively high price of the plastic are keeping it from penetrating the market [34, 39].

Cellulose derivatives are polymers that are based on the polysaccharide cellulose. Cellophane – which is, technically speaking, not a plastic – is transparent and is made up of short cellulose fragments that can be chemically modified to make them soluble and thus malleable. The material cannot be melted or deformed under heat and pressure due to the high number of hydroxyl groups and the resulting presence of hydrogen bonds. Accordingly, it is not heat-sealable; on account of its composition, it is also water-sensitive. For this reason and because of the relatively high costs, cellophane is usually coated with other plastics or even replaced by them [32, 34, 42].

Cellulose acetate (CA), on the other hand, is heat-sealable and much more stable with regard to moisture due to acetyl groups and the resulting reduced number of hydrogen bonds and plasticisers. However, the barrier properties are lower compared to cellophane [32, 34, 42].

Polybutylene succinate (PBS) is produced as a polyester by the synthetic reaction of the source materials succinic acid and butanediol. The material can be produced both petrochemically and fermentatively on the basis of renewable raw materials such as glucose. The material is suitable for the production of films, bottles and other packaging. PBS is similar to the conventional plastics PP and LDPE (low density polyethylene). In addition, PBS can be combined with materials such as PLA, PHA and TPS during production [39].

Petro-based and biodegradable

Polycaprolactone (PCL) is produced on the basis of a polyester compound, usually involving the use of petro-based source materials. Due to the comparatively low decomposition temperatures, a mixture of PCL and amorphous PLA is commonly used [43].

Polybutylene adipate terephthalate (PBAT) is also a polyester compound that is biodegradable and compostable and, like PCL, is usually produced from petro-based source materials. It is often used in combination with other bio-based plastics. Similar to LDPE, it is used as a film and can be processed by means of standard methods. It has a high barrier against water vapour [43].

Inspection and labelling of degradable plastics

Degradation, or decomposition, affects all materials and ultimately results in the loss of material properties and structure. Its speed and extent are directly dependent on the respective environmental conditions. The underlying mechanisms can be divided into chemical-physical and biological. We can thus distinguish between degradability and biodegradability. This distinction is important because not every material that is no longer visible to the naked eye after a few weeks has actually biodegraded (see oxodegradability, page 13).

The materials can degrade in different ways. In photodegradation, electromagnetic radiation (especially (UV) light) causes photooxidation and bond cleavage, resulting in a reduction in the molecular weight of polymers. The material becomes brittle and decomposes. In biological degradation, however, microorganisms use the material as a substrate and convert it into water, CO2 and biomass [16].

Composting is an accelerated degradation of heterogeneous organic matter by a microflora in a humid, warm and aerobic environment under controlled conditions. The usual composting temperatures are between 40° and 70°C. A plastic is compostable if it degrades by biological processes during a composting process. This produces CO2, water, inorganic compounds and biomass at a rate similar to that of other known compostable materials, leaving no visually distinguishable or toxic residues. All compostable plastics are therefore biodegradable. Conversely, a biodegradable material is not necessarily compostable [16].

As for the inspection and labelling of bio-based plastics, there are already standards and certification options regarding the degradability of plastics (e. g. OK-Compost, DIN-tested, DIN EN 13432:2000-12, DIN EN 14995:2007-03, DIN EN ISO 472:2013-06, ASTM D883-19c).

Oxodegradable plastics constitute a special category. In this process, petro-based plastics are mixed with additives that cause decomposition in the environment and allow the materials to fragment quickly after use. Polyolefin plastics typically contain prodegradants (e. g. metal salts such as iron, cobalt, manganese) to catalyse these decomposition reactions. However, this material property only solves our problem of finding plastic in macro form in the environment. However, it is different from biological degradation according to the applicable standard, since in this case the material is not completely decomposed by microorganisms. It is therefore also not a "bioplastic". From an environmental and legal point of view, it is not advisable to use these materials. The reason is that they contaminate the environment and thus entail the deliberate production of microplastics. In addition, the additives used would damage other materials if they were fed into a recycling process. Nevertheless, the marketing of oxodegradable plastics will be banned starting in July 2021 within the framework of the Disposable Plastics Directive (Directive (EU) 2019/904), which came into force in 2019 [16].

USE OF BIOPLASTICS IN FOOD PACKAGING

Bioplastics are well suited for food packaging. However, their field of application and the possibility of replacing conventional plastics largely depend on the respective material properties. While drop-in plastics can be used for the same applications as their conventional counterparts due to their identical chemical structure, other bioplastics are mainly challenged by lower barrier properties, which can be advantageous or disadvantageous depending on the product properties. In addition, the mechanical properties, some of which differ, must also be taken into consideration. It is therefore advisable to perform a comparison between product requirements and properties of the materials or the packaging made from them [35, 42, 44]. The exact foods and their requirements are set out in the specialised literature [16, 17, 44, 45]. Table 2 (page 14 and 15) also provides an overview of the use of various bioplastics in food packaging.

In general, PE and PP, whether conventional or bio-based, offer a high water vapour barrier and flexibility. If, on the other hand, a low water vapour barrier and flexibility are required, starch-based plastics or biodegradable polyesters can generally be used. In cases where transparency, rigidity and barrier are required, PLA with a silicon oxide (SiOx) barrier layer, for example, can also be used instead of (bio-)PET or a composite material. If only transparency and stiffness are required, PLA without a coating can be used instead of polystyrene (PS), PP and (bio-)PET. Alternatively, a high level of stiffness can also be achieved with starch blends or other materials such as paper and cardboard. In general, however, it must be pointed out that the use of coatings, blends and the like can result in different behaviour of the degradability of the packaging or its recyclability and must be inspected [35].

In order to continue improving the functionality of bioplastics and thus primarily the mechanical and barrier properties of bioplastics, current research is mainly concerned with the topics of coatings, blends and the chemical or mechanical modification of materials. Research is also continuing to address new bioplastics and the use of alternative sources of raw materials [42].

ENVIRONMENTAL ASPECTS OF BIOPLASTICS

Whether bio-based, biodegradable or both – the extent to which the use of bioplastics in packaging is helping to develop a sustainable future is currently being discussed from different points of view. However, it is important to recognise that we cannot make general statements and that a detailed assessment of the advantages and disadvantages must be carried out in each case.

Table 2: Bioplastics and their use in food packaging (table created based on [39])

Bioplastic	Flexible packaging	Rigid packaging	Hollow bodies (e. g. bottles)	Other
Bio-polyolefins (bio-PE, bio-PP), bio-PET	Conventional fields of application			
	· Bags · Films	· Cups · Trays	Bottles	· Composite materials (paper) · Disposable items · Closures and caps (PE, PP)
Starch-based polymers	· Fruit and vegetables (e. g. potatoes and carrots)	· Fruit and vegetables · Coffee	–	Miscellaneous
	· (Transparent) bags · Mulch films	· Cups · Trays · Coffee capsules	–	· Fillers · Disposable items · Labels
PLA	· (Sliced) Fruit and vegetables · Bread · Pasta · Spices · Snacks	· (Sliced) Fruit and vegetables · Bread · Salads · Dairy products · Meat products · Frozen/refrigerated products (e. g. chips) · Beverages · To-go products	· Refrigerated products with a short shelf life · Dairy products · (Carbonated) Beverages (e. g. juice, water)	Coffee and tea
	· Bags · Shrink films · Composite materials (for products with a longer shelf life)	· Cups · Trays · Storage of empty packaging at high temperatures should be avoided	· Bottles · Sealing caps for wine bottles · Not the preferred material, barrier required for further applications	· Compostable tea bags and coffee capsules · Composite materials (paper) for coffee cups, etc. · Disposable items · Foamed trays and additional containers

Table 2: Bioplastics and their use in food packaging (table created based on [39])

Bioplastic	**Flexible packaging**	**Rigid packaging**	**Hollow bodies (e. g. bottles)**	**Other**
PHA	Fresh foods	Frozen Products	–	–
	–	–	–	–
Cellulose derivatives	· Confectionery · Fruit and vegetables (e. g. kiwis, tomatoes, paprika) · Meat · Fish · Dairy products · Bread · Pasta · Coffee	–	–	–
	· Confectionery wrappers (e. g. sweets) · Cellophane film for fruit and vegetables · Composite materials (for products with a longer shelf life)	–	–	· Cellulose acetate · Disposable items
Other bio-degradable polyesters	· Fruit · Vegetables · Frozen products	· Fruit · Vegetables	–	–
	Bags	–	–	· Biodegradable nets · Composite materials (paper) · Foamed items · Capsules (coffee)

Possible advantages of bioplastics in the public debate include the reduced dependence on fossil resources, reduced greenhouse gas emissions, the efficient use of renewable resources, reduced environmental pollution and biodegradability/composting. However, when we consider various lifecycle analyses, which are sometimes difficult to prepare due to methodological challenges and often inadequate data, it becomes clear that there are only partial advantages in the categories of climate change, fossil resource consumption and energy as well as energy expenditure, but that other categories (e. g. acidification, eutrophication, toxicity, land and water consumption) generally perform less well. Furthermore, there may be a point of conflict regarding competition with food production. Accordingly, the calls for bioplastics originating from certified sustainable cultivation or from residues or by-products of the agricultural or food sector, are becoming louder and louder. The danger of shifting the burden and possibly of "greenwashing" is therefore real and should be prevented wherever possible.

With regard to the end of life of packaging made of bioplastics, it must be pointed out that European efforts and developments to date will be placing a strong emphasis on recyclability. Consequently, there are hardly any hurdles to be expected for drop-in plastics, as there are already collection and recycling flows in place. However, in the case of plastics such as PLA or PHA, which are generally recyclable, it is questionable whether such flows will exist in the future. In the absence thereof, due, for example, to insufficient absolute quantities, an inadequate definition of the recyclability or lack of recovery flows, this could be a significant obstacle to the further development of these plastics. Although the aim is to achieve recyclability, there will still be packaging in the future (e. g. composite materials in special applications) that is not recyclable but is advantageous in the lifecycle analysis. For these and potentially for bioplastics, energetic use could therefore make sense. Another possibility is to compost biodegradable plastics. However, it should be noted that composting does not result in high-quality fertiliser and that the industrial composting plants currently in operation are not generally designed to recycle these plastics. There is an additional benefit of biodegradable plastics if they are subject to the risk of not being collected or recycled or if they are likely to remain in the environment or become litter. With regard to the problem of litter, i.e. the pollution of the environment in the form of carelessly discarded waste, it should be added that the use of bioplastics is unlikely to contribute to a change in the behaviour of those responsible [6, 17, 39, 44, 46, 47, 48, 49].

CONCLUSION AND OUTLOOK

Although (food) packaging is facing some environmental challenges, such as pollution, it must also receive credit for the fact that it makes a valuable contribution to supply security and food safety; in many cases it helps to prevent food loss and food waste and the negative environmental impact involved. Our ultimate aim should therefore be, in addition to reducing the use of packaging material to the necessary minimum, to use effective packaging which, in terms of its functions and material properties, is aligned with the respective product and its lifecycle. Furthermore, packaging should be optimised in terms of recyclability and safety in order to produce sustainable packaging as part of the overall solution.

Like any other material, plastics have advantages and disadvantages when used as packaging materials. Due to environmental pollution and other challenges, the current topics are recycling management, the reduction of the use of plastics and possibilities for substitution. In light of these issues, bioplastics are also a topic of constant discussion. It is essential in this context that we make a clear distinction between bio-based but not biodegradable (e. g. drop-in plastics such as bio-PET), bio-based and biodegradable (e. g. PLA) as well as petro-based and biodegradable (e. g. PBAT) plastics and that there is clear communication, as the term “bioplastics” is often unclear, especially for ordinary people. In addition, we must recognise that bio-based materials, biodegradable materials or bioplastics in general cannot automatically be equated with sustainability; due to the large number of influencing factors, we need a lifecycle analysis to be able to make well-founded statements.

While drop-in bioplastics fully correspond to their conventional counterparts in terms of their properties and therefore their suitability for use as food packaging, the other bioplastics differ to some extent from those of conventionally used plastics in their material and barrier properties. Depending on the product and its requirements, this can be seen as both an advantage and a disadvantage. In general, however, it can be said that bioplastics are generally suitable for use as food packaging.

Currently, bioplastics are playing only a minor but growing role in the plastics market. The continued development of the market will depend on various factors. These include environmental factors and food competition as well as legal framework conditions, acceptance by target groups, suitability for use and costs.

Research, development and innovation can therefore be expected particularly in the field of bioplastics themselves, but also in the fields of bioeconomics, collection and recovery structures, recycling processes and new business models.

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BIBLIOGRAPHY

[1] Food and Agriculture Organization of the United Nations 1 (s. a.): Food Loss and Food Waste. URL: http://www.fao.org/food-loss-and-food-waste/en/ (Accessed on 08.09.2019)

[2] Gustavsson J., Cederberg C., Sonesson U., Van Otterdijk R., Meybeck A. (2011): Global food losses and food waste. Extent causes and prevention. FAO. Rome, Italy. URL: http://www.fao.org/3/a-i2697e.pdf (Accessed on 01.10.2019)

[3] Xue l., Liu G., Parfitt J., Liu X., Van Herpen E., Stenmarck Å., O'Connor C., Östergren K., Cheng S. (2017): Missing Food, Missing Data? A Critical Review of Global Food Losses and Food Waste Data. Environmental science & technology 51 (12): S 6618–6633

[4] Stenmarck A, Jensen C., Quested T., Moates G. (2016): Estimates of European food waste levels. IVL Swedish Environmental Research Institute

[5] Denkstatt (2018): Nutzen von Verpackungen: „Verpackungen nutzen – auch in ökologischer Hinsicht". AGVU Arbeitsgemeinschaft Verpackung und Umwelt e.V. Mainz, Germany. URL: https://denkstatt.eu/download/10272/?lang=de (Accessed on 08.09.2019)

[6] Verghese K., Helen L., Leanne F. (2012): Packaging for Sustainability. Springer Science & Business Media. London, England

[7] Anonymous A (s. a.): EU Platform on Food Losses and Food Waste. URL: https://ec.europa.eu/food/safety/food_waste/eu_actions/eu-platform_en (letzter Zugriff 08.09.2019)

[8] Vittuari M., Azzurro A., Gaiani S., Gheoldus M., Burgo S., Aramyan L., Valeeva N., Rogers D., Östergren K., Timmermans T., Bos-Brouwers H. (2016): Recommendations and guidelines for a common European food waste policy framework. Fusions. Bologna, Italy

[9] Anonymous B (s. a.): Initiative Save Food. Solutions for a world aware of its resources. URL: https://www.save-food.de/ (Accessed on 08.09.2019)

[10] Timmermans A. J. M., Ambuko J., Belik W., Huang J. (2014): Food losses and waste in the context of sustainable food system. 8. No. A report by The High Level Panel of Experts on Food Security and Nutrition. Rome, Italy

[11] Anonymous C (2019): Circular Economy. Implementation of the Circular Economy Action Plan. Final Circular Economy Package. URL: https://ec.europa.eu/environment/circular-economy/index_en.htm (Accessed on 08.09.2019)

[12] Anonymous D (2019): European strategy for plastics. URL: https://ec.europa.eu/environment/waste/plastic_waste.htm (letzter Zugriff: 08.09.2019)

[13] Anonymous E (2019): Klimapolitik. URL: https://ec.europa.eu/clima/index.de (Accessed on 08.09.2019)

[14] CPP, Institute of Packaging Professionals, Soroka W. (2014): Fundamentals of Packaging Technology. The Definitive Resource on Packaging Technology. 5. No. Institute of Packaging Professional

[15] Berndt H. E. D., Demanowski H., Dreher M., Hennig J., Herzau M., Herzau E., Kaßmann M., Lange V., Roeber K., Rommel C., Sellschopf L., Ströhmer M., Volkmann F., Weiß U. (2014): Grundlagen der Verpackung. Leitfaden für die fächerübergreifende Verpackungsausbildung. Ed. Kaßmann M., DIN Deutsches Institut für Normung e.V. 2. No. Dresden, Germany. Beuth Verlag GmbH

[16] Robertson G. L. (2013): Food Packaging Principles and Practice. 3. No. Boca Raton, United States. CRC Press

[17] Singh P., Wani A. A., Langowski H.-C. (2017): Food Packaging Materials: Testing & Quality Assurance. 1. No. Boca Raton, United States. CRC Press

[18] Bergmair J., Washüttl M., Wepner B. (2012): Prüfpraxis für Kunststoffverpackungen: Lebensmittel-, Pharma- und Kosmetikverpackungen. 2. No. Hamburg, Germany. Behr's Verlag DE

[19] Herzau E., Kaßmann M., Volkmann F. (2010): Verpackungsprüfung. 1. No. Dresden, Germany. Beuth Verlag GmbH

[20] Yam K. L. (2010): The Wiley Encyclopedia of Packaging Technology. 3. No. s.l. John Wiley & Sons

[21] Campbell-Platt G. (2017): Food Science and Technology. 2. No. UK. John Wiley & Sons

[22] Carlsson D. J. & Wiles D. M. (1986): In H. F. Mark, N. M. Bikales, C. G. Overberger, & G. Menges (Eds.), Encyclopedia of polymer science and engineering. Vol. 4. (pp. 665). New York: John Wiley & Sons

[23] EU-Kommision (2011): VERORDNUNG (EU) Nr. 10/2011 DER KOMMISSION, vom 14. Januar 2011 über Materialien und Gegenstände aus Kunststoff, die dazu bestimmt sind, mit Lebensmitteln in Berührung zu kommen (Text von Bedeutung für den EWR). https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:012:0001:0089:DE:PDF (Accessed on 01.10.2019)

[24] Cengiz C. (2017): Fundamentals of the Sorption (Scalping) Phenomena in Packaged Foods. DOI: 10.1016/B978-0-08-100596-5.22346-9

[25] Barone C., Bolzoni L., Caruso G., Montanari A., Parisi S., Seinka I. (2015): Food Packaging Hygiene. Springer International Publishing

[26] Rezaei J., Papakonstantinou A., Tavasszy L., Pesch U., Kana A. (2018): Sustainable product-package design in a food supply chain: Amulti-criteria life cycle approach. Packaging Technology and Science 32 (2): S 85–101

[27] Robertson M. (2017): Sustainability-principles and practice. Routledge. 2. No. London, England. Routledge

[28] Anonymous F (2019): Sustainability Development Goals. URL: https://sustainabledevelopment.un.org/?menu=1300 (Accessed on 08.09.2019)

[29] Hellström D., Olsson A. (2017): Managing Packaging Design for Sustainable Development: A Compass for Strategic Directions. 1. No. Oxford, UK. John Wiley & Sons

[30] Lewis H., Fitzpatrick L., Verghese K., Sonneveld K., Jordon R. (2007): Sustainable Packaging Redefined. Sustainable Packaging Alliance

[31] Erlöv L. (2000): Packaging: A Tool for the Prevention of Environmental Impact. s. l. Packforsk

[32] Baur E., Brinkmann S., Osswald T. A., Rudolph N., Schmachtenberg E. (2013): Saechtling Kunststoff Taschenbuch. 31. No. München, Germany. Hanser Verlag

[33] Plastics Europe (2018): Plastics – the Facts 2018. An analysis of European plastics production, demand and waste data. URL: https://www.plasticseurope.org/de/resources/publications/670-plastics-facts-2018 (Accessed on 08.09.2019)

[34] Selke S. E., Culter J. D. (2016): Plastics packaging: properties, processing, applications, and regulations. 3. No. Ohio, United States. Carl Hanser Verlag GmbH Co KG

[35] Van den Oever M., Molenveld K., Van der Zee M., Bos H. (2017): Bio-based and biodegradable plastics – Facts and Figures. Focus on food packaging in the Netherlands. DOI: 10.18174/408350

[36] European Bioplastics (2016): Fact Sheet. What are bioplastics? Material types, terminology, and labels – an introduction. URL: https://docs.european-bioplastics.org/2016/publications/fs/EUBP_fs_what_are_bioplastics.pdf (Accessed on 08.09.2019)

[37] All4Pack (2018): Market key figures, challenges & perspectives of worldwide packaging. URL: https://www.all4pack.com/Media/All-4-Pack-Medias/Files/FicheMarche_Emballage_Monde (Accessed on 08.09.2019)

[38] Endres H. J., Siebert-Raths A. (2009): Technische Biopolymere: Rahmenbedingungen. Marktsituation, Herstellung, Aufbau und Eigenschaften. München, Germany. Carl Hanser Verlag

[39] Greene J. P. (2014): Sustainable Plastics: Environmental Assessments of Biobased, Biodegradable, and Recycled Plastics. s. l. John Wiley & Sons

[40] CHEmanger (2017): Industriekonsortium erhält Fördermittel für Polyethylenfuranoat (PEF). URL: https://www.chemanager-online.com/news-opinions/nachrichten/industriekonsortium-erhaelt-foerdermittel-fuer-polyethylenfuranoat-pef (Accessed on 08.09.2019)

[41] Jamshidian M., Tehrany E. A., Imran M., Jacquot M., Desobry S. (2010): Poly-Lactic Acid: Production, Applications,Nanocomposites, and Release Studies. Comprehensive reviews in food science and food safety 9 (5): S 552–571

[42] Peelman N., Ragaert P., De Meulenaer B., Adons D., Peeters R., Cardon L., Van Impe F., Devlieghere F. (2013): Application of bioplastics for food packaging. Trends in Food Science & Technology, 32 (2): S 128–141

[43] Jawaid M., Swain S. K. (2018): Bionanocomposites for packaging applications. s. l. Springer International Publishing

[44] Detzel A., Bodrogi F., Kauertz B., Bick C., Welle F., Schmid M., Schmitz K., Müller K., Käb H. (2018): Biobasierte Kunststoffe als Verpackung von Lebensmitteln. Endbericht. Bundesministerium für Ernährung und Landwirtschaft Heidelberg, Freising, Berlin

[45] Robertson G. L. (2009): Food Packaging and Shelf Life: A Practical Guide. Boca Raton, United States. CRC Press

[46] Yates M. R., Barlow C. Y. (2013): Life cycle assessments of biodegradable, commercial biopolymers - A critical review. Resources, Conservation and Recycling, 78: S 54–66

[47] Hottle T. A., Bilec M. M., Landis A. E. (2017): Biopolymer production and end of life comparisons using life cycle assessment. Resources, Conservation and Recycling, 122: S 295–306

[48] Rossi V., Cleeve-Edwards N., Lundquist L., Schenker U., Dubois C., Humbert S., Jolliet O. (2015): Life cycle assessment of end-of-life options for two biodegradable packaging materials: sound application of the European waste hierarchy. Journal of Cleaner Production, 86: S 132–145

[49] Deutsche Umwelthilfe (2018): Bioplastik in der Kompostierung. Ergebnisbericht – Umfrage. URL:https://www.duh.de/fileadmin/user_upload/download/Projektinformation/Kreislaufwirtschaft/Verpackungen/180920_DUH_Ergebnisbericht_Kompostierungsumfrage.pdf (Accessed on 08.09.2019)

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