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Engineering Biopolymers

Markets, Manufacturing, Properties and Applications

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Table 5.2 Predrying Requirement Prior to Processing

Material	Predrying required
PCL	no
Bio-polyester	yes/no*
PHAs	yes/no*
PLA	yes
PLA blends	yes/no*
Starch blends	yes/no*
Cellulose derivate	yes
PE	no
PP	no
ABS	yes
PET	yes

*Predrying is not mandatory, yet advisable

taken, the solidification rate of PLA is typically still a slightly higher than that of PP, PE and especially ABS.

5.2.1.4 Economic Aspects

The heteroatoms oxygen and nitrogen present in the chain of biopolymers as well as in ABS and in particular in PET e.g. lead to a significant increase in density compared to PE-HD and PP (see Fig. 5.49). That is why the density of biopolymers is only slightly lower than the density of PET. This means that at a price per kg, significantly less biopolymer material (volume) can be purchased compared with PE or PP; somewhat less material can be purchased compared with ABS, and slightly more compared with PET.

The current *material prices* (see Fig. 5.50) for biopolymers range from 1.6 to almost 13 €/kg. On average, though, the prices range from 1.6 to 6 €/kg. Currently, the most economical biopolymers are PLAs priced as low as 1.6 to 1.9 €/kg and various starch blends with prices starting at 2 €/kg. Polyesters and PHAs are currently available for as low as 3 €/kg, and the authors believe the price will decrease even further in the future. The cost of raw materials is certainly only one reason for the currently somewhat higher material prices. Once increasing demand leads to significant scale-up in production, the price of biopolymers will continue to decrease. Currently, the use of biopolymers is economical only when the costs of disposal for conventional plastics, i. e., the ecological disposal advantages of biopolymers, are taken into consideration (cf. Section 1.3). In the future, however, continued demand for petrochemical

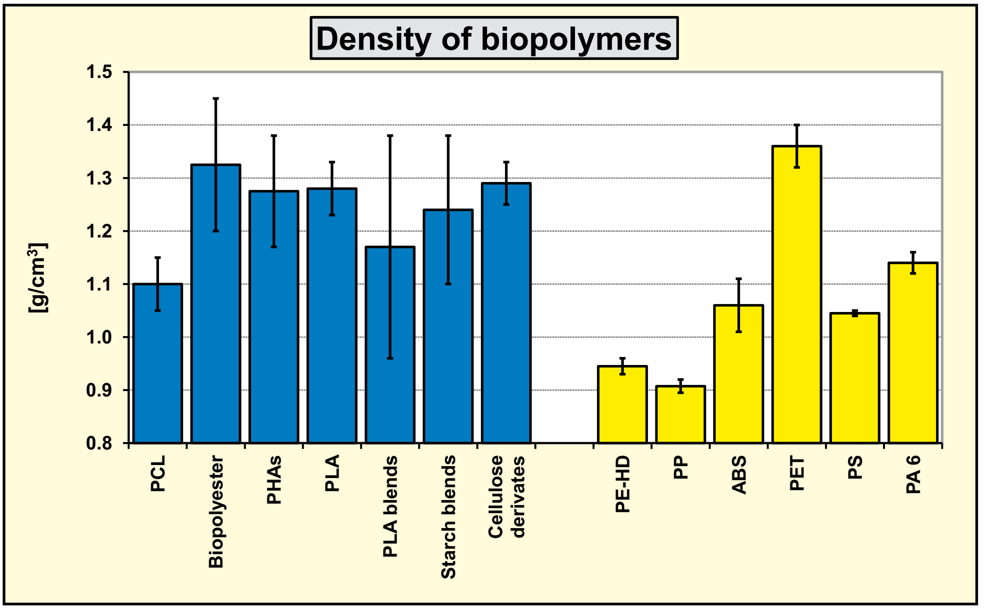

Figure 5.49 Density of various biopolymers compared with various conventional plastics (data for conventional plastics in part according to [24, 25, 69], detailed values for the biopolymers, see Appendix)

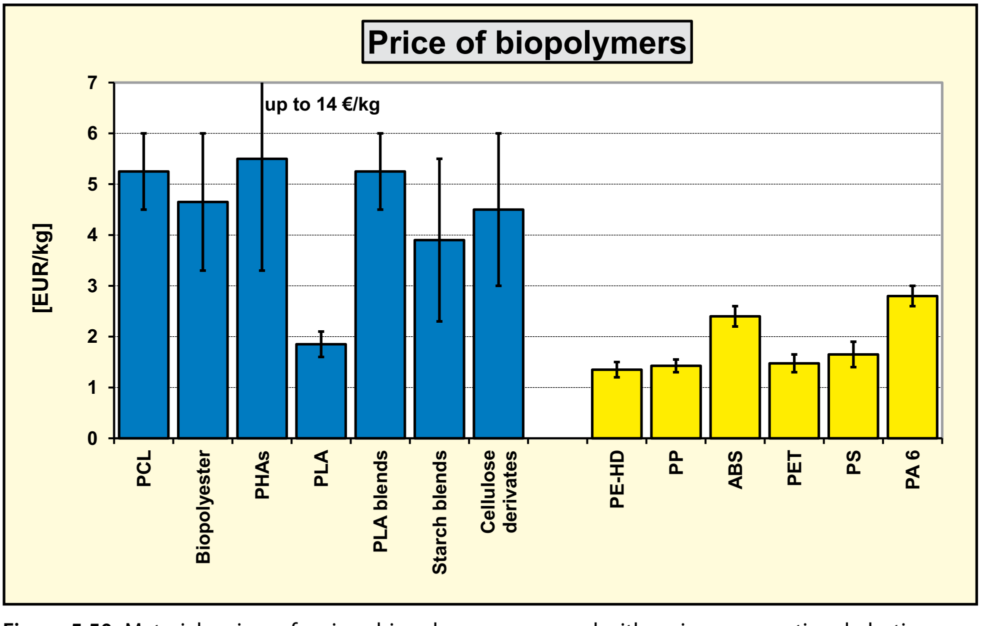

Figure 5.50 Materials prices of various biopolymers compared with various conventional plastics (data for conventional plastics in part according to kiweb)

based polymers will lead to increased prices for petrochemical feedstock, whereas increasing demand for biopolymers will tend to reduce materials prices for biopolymers due to the expanded industrial scope of manufacturing.

This means that the prices for biopolymers, currently 1.5 to 3.5 times higher than those of conventional plastics, will probably be comparable in the near future (cf. also Fig. 1.22).

5.2.1.5 Specific Pricing Information

When comparing prices, consideration must also be given to the higher density of biopolymer materials. This is due to the additional heteroatoms incorporated in their molecular structure, while absent in PE or PP e.g. In other words, as material density increases, the same money buys less material, because the prices quoted for pellets are usually based on weight. Figures 5.51 and 5.52 show mass-specific and volume-specific prices for various biopolymers compared with various conventional plastics. It turns out that the higher prices of biopolymers together with their higher density result in higher mass-specific and particularly in higher volume-specific prices.

Price comparisons should not be limited to a direct comparison of pure weight-based material prices. This applies to comparisons of biopolymers with conventional plastics as well as to comparisons of plastics of the same type. By including the respective benefits in the consideration it is ensured that the costs of various biopolymers for a particular use are compared with those of conventional plastics offering the same benefits for the intended application. Despite their somewhat higher density, biopolymers perform better on the whole than the bulk plastics PE and PP thanks to their higher-level properties, as shown by the comparative Figs. 5.53 and 5.58.

Here it should be pointed out that, when comparing biopolymers with conventional plastics, it is misleading to compare, e. g., the mechanical properties of biopolymers with those of

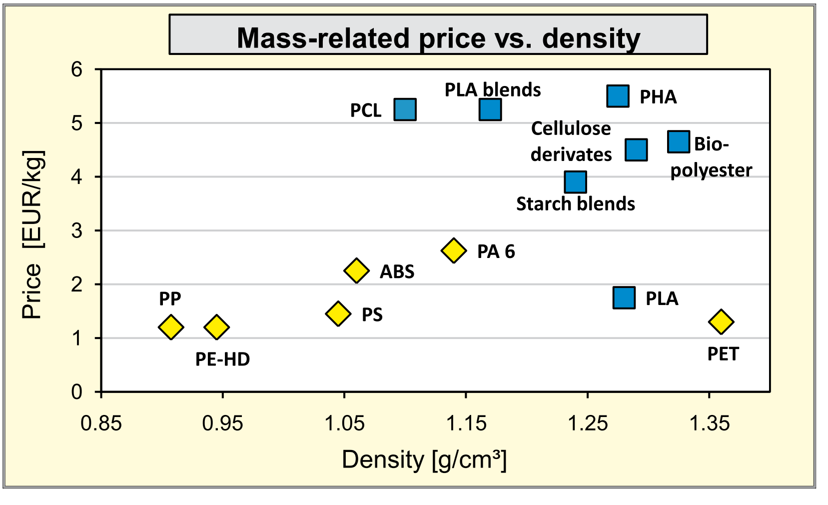

Figure 5.51 Materials prices of various biopolymers compared with conventional plastics (by weight)

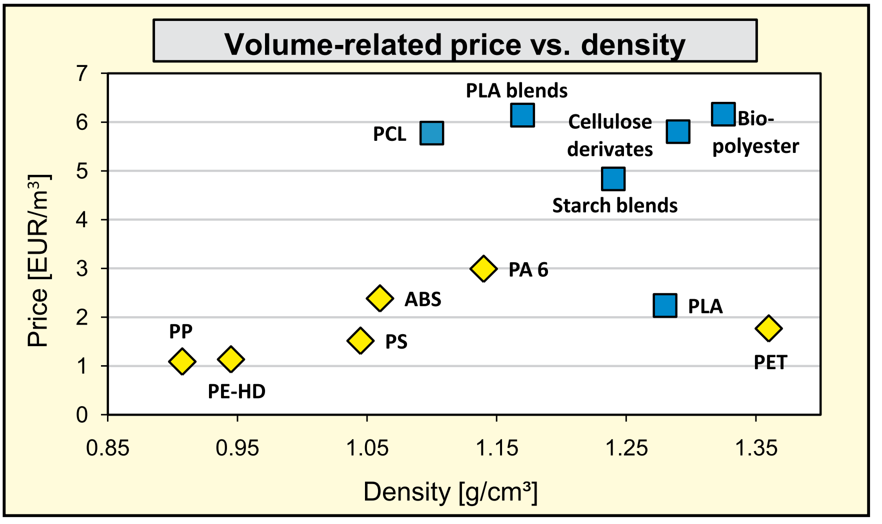

Figure 5.52 Materials prices of various biopolymers compared with conventional plastics (by volume)

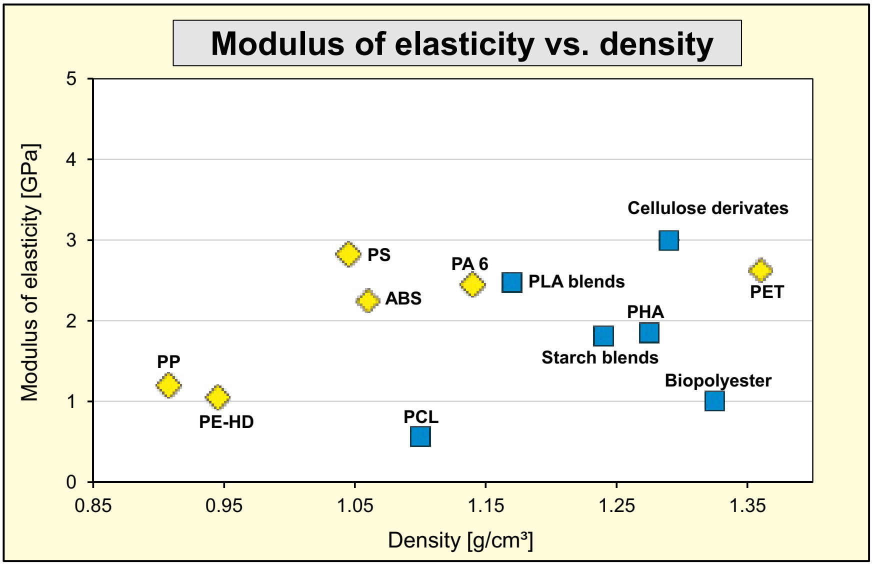

Figure 5.53 Modulus of elasticity versus density for various biopolymers compared with conventional plastics (data for conventional plastics in part according to [24, 25, 69], detailed values for the biopolymers, see Appendix)

engineering plastics and on the other hand, when comparing prices or densities, to include the light-weight bulk plastics PE and PP.

Comparing modulus of elasticity versus density (see Fig. 5.53) for various biopolymers, the general relationship (modulus of elasticity increases with increasing density) holds for bio-

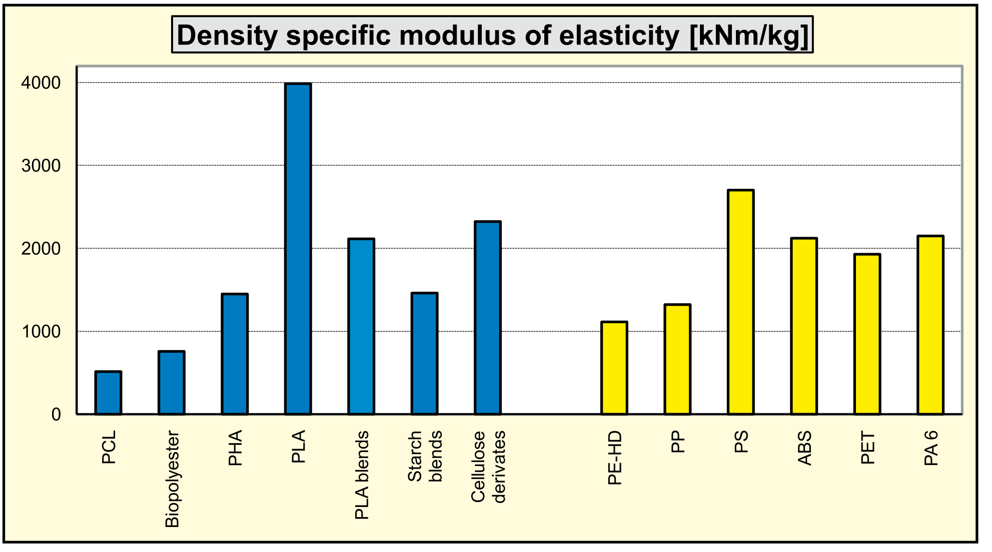

Figure 5.54 Density specific modulus of elasticity (modulus of elasticity/density) of various biopolymers compared with conventional plastics

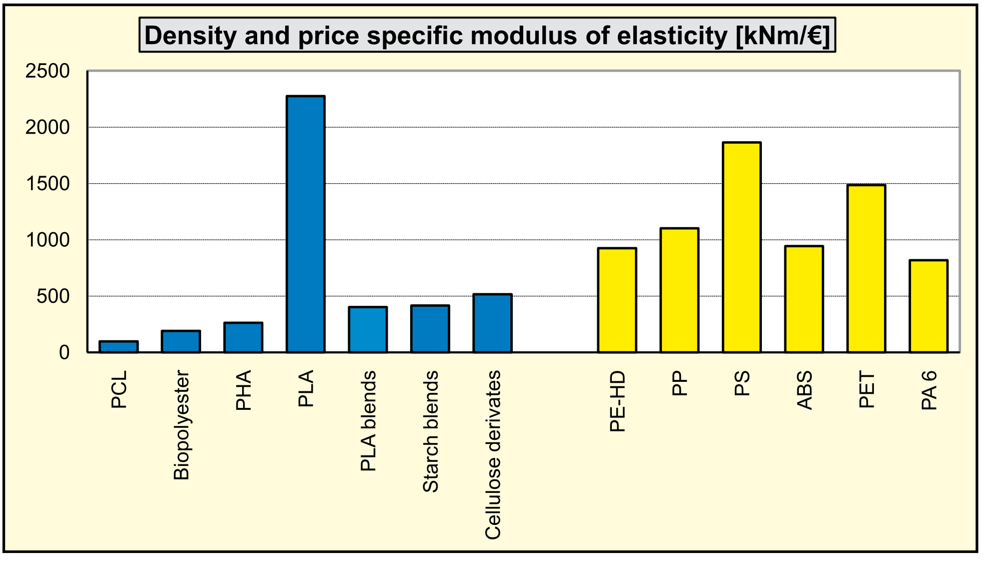

Figure 5.55 Density and price specific modulus of elasticity (modulus of elasticity/(density × price)) of various biopolymers compared with conventional plastics

polymers just as for conventional plastics. Noteworthy here in particular is the high elastic deformation resistance of PLA.

In order to compare the various materials, the costs should be seen in direct relationship with benefits and the particular use, e. g. by considering the ratio of modulus of elasticity to density.

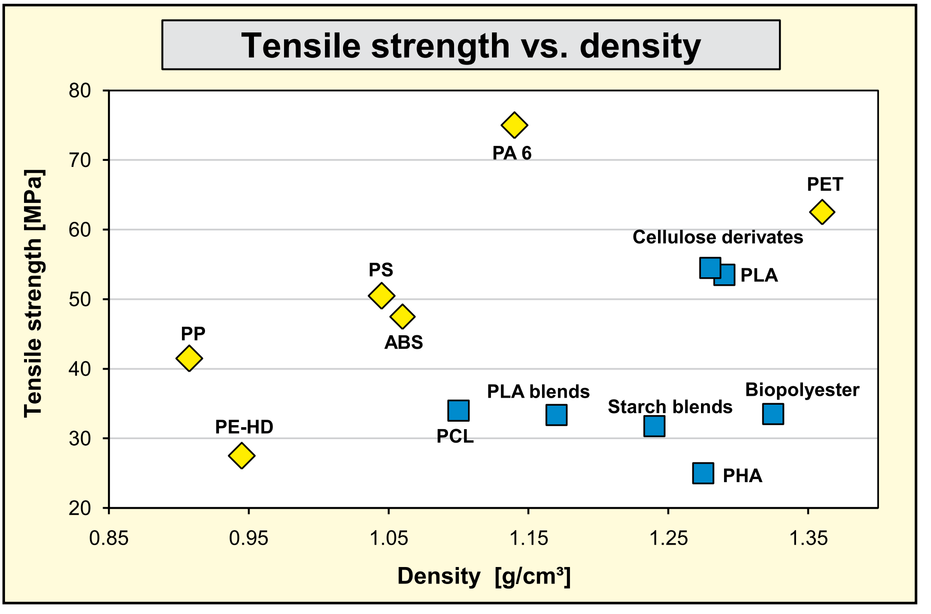

Figure 5.56 Tensile strength versus density for various biopolymers compared with conventional plastics (data for conventional plastics in part according to [24, 25, 69], detailed values for the biopolymers, see Appendix)

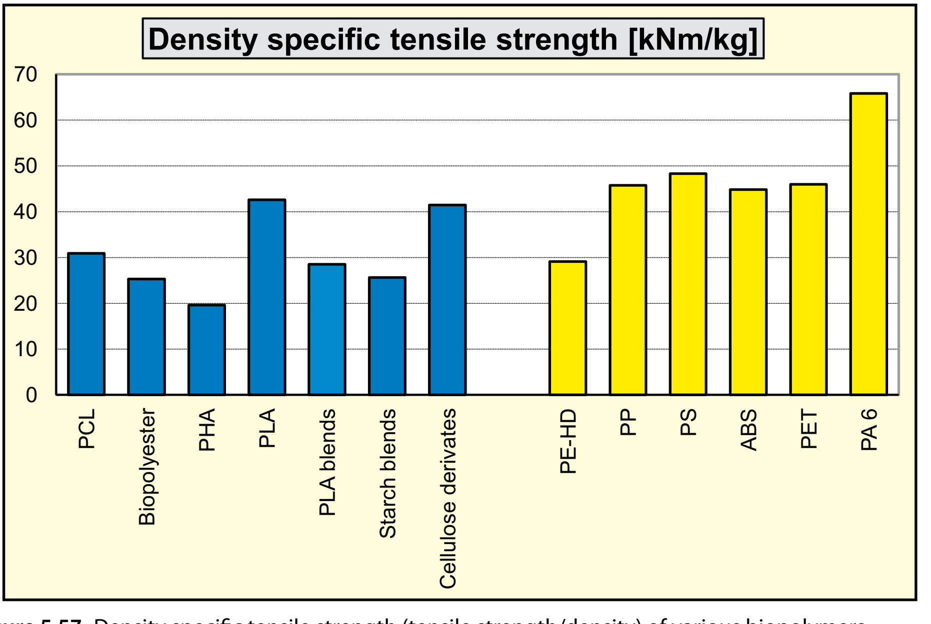

Figure 5.57 Density specific tensile strength (tensile strength/density) of various biopolymers compared with conventional plastics

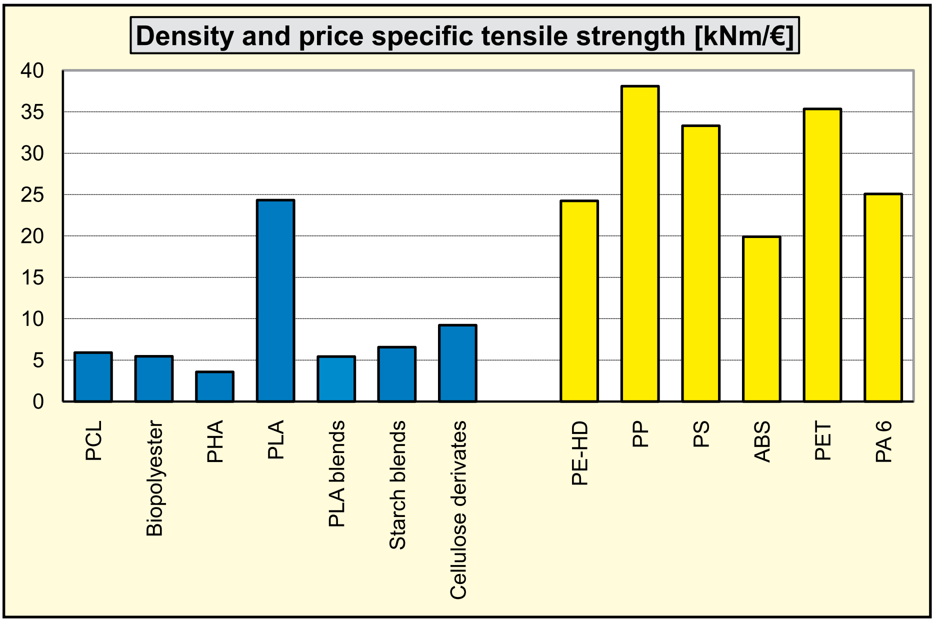

Figure 5.58 Density and price specific tensile strength (tensile strength/(density × price)) of various biopolymers compared with conventional plastics

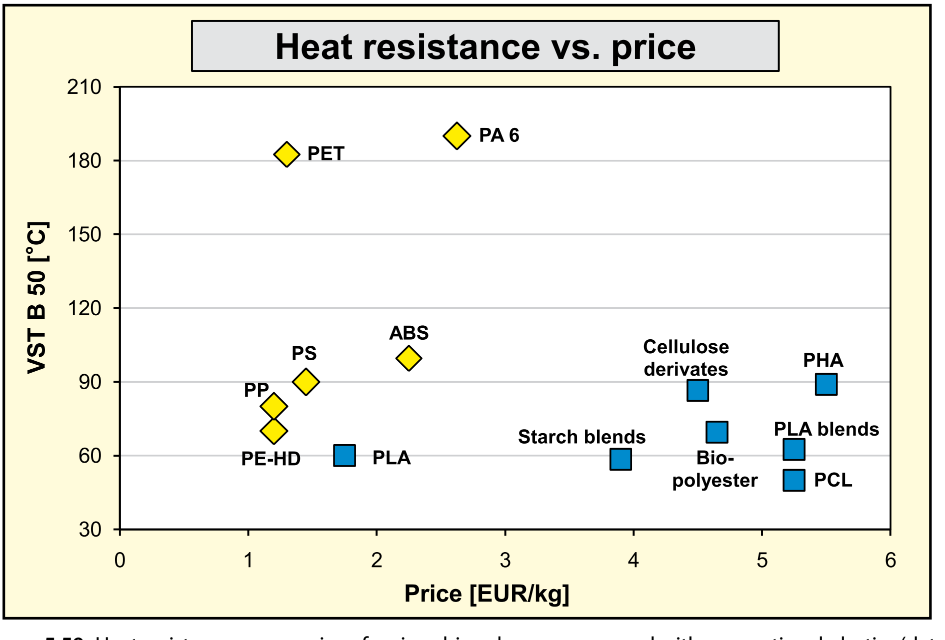

Figure 5.59 Heat resistance versus price of various biopolymers compared with conventional plastics (data for conventional plastics in part according to [24, 25, 69], detailed values for the biopolymers, see Appendix)

Despite its higher density, PLA provides the highest density-specific modulus of elasticity due to its high stiffness (see Fig. 5.54). The specific modulus of elasticity is a measure for absorbable deformation energy per kilogram of material. If the mass-specific price of the material is also used as a benchmark, PLA stands out against the reference materials, and especially against the other biopolymers, in term of density- and price-specific modulus of elasticity as a measure of absorbable deformation energy per Euro (see Fig. 5.55). As efforts continue to develop biopolymers as materials for engineering applications beyond the field of packaging materials, increasingly stiffer and stronger polyesters or bio-PAs will be developed.

These advantageous properties of PLA compared to conventional plastics include in particular their elastic deformation resistance under tensile or bending load. When tensile strength is considered, PLA and cellulose derivates also stand out against other biopolymers (see Fig. 5.56). Compared to conventional plastics, PLA and cellulose derivates exhibit density-specific strengths, as well as density- and price-specific strengths that are "only" comparable with the values for conventional plastics (see Fig. 5.57).

Considering heat resistance versus price, Fig. 5.59 shows how much heat resistance 1 € will buy. The heat resistance characteristics of biopolymers remain unsatisfactory, while their material price is slightly higher than the price for conventional plastics.

5.2.2 Materials for Biopolymer Film

The following properties will be given closer consideration in the comparison of biopolymer film materials with typical, conventional packaging plastics:

- approval for direct contact with food
- certification of compostability
- barrier properties (water vapor, oxygen and CO_2 permeability)
- physical-chemical properties (transparency, lightfastness, antistatic, etc.)
- characteristic mechanical values for films
- processing properties of biopolymer films
- economic aspects regarding biopolymer films

5.2.2.1 Approval for Direct Contact with Food

The packaging industry offers a wide variety of applications for biopolymers; from applications in the food industry to agricultural applications (mulch films, landscape films), to office supplies (windows in envelopes, folders), and as carrier or garbage bags

In food packaging applications, films often have direct contact with the food. Therefore, it must be ensured that the packaging material has no negative effect on the food, i. e., in particular that no volatile or harmful components (e. g., external plasticizers) migrate from the packing material into the packaged goods. For this reason, films and polymers have to have approval for contact with food. In Europe the basis for approval is the EU Commodities Regulation (currently: no. 1935/2004). The approval process for food contact is intended to ensure that human health is not endangered by packaging materials, i. e., substances migrating out of the packaging material into food. All details for applying for approval for food contact and testing for compliance with maximum permissible values for migration are described in VO 1935/2004 and in Guideline 2002/72/EU (Food-Plastic Guideline). They also list all basic monomers and other basic substances approved for use in contact with food.

For most conventional plastics, there are corresponding "positive lists" of materials approved for food contact that are based on previously performed investigations and many years of experience. These lists also often differentiate between different foods to be packaged (solid, liquid, acid, fatty, etc.). For innovative materials approval for food contact has to be sought, and the tests required involve a corresponding amount of time and financial expense.

The following list includes all those biopolymers for which manufacturers claim they have already obtained approval for food contact. Further details on biopolymer materials approved for food contact can be found in the appendix as well as in the biopolymer database.

Table 5.3 Biopolymers Approved for Applications with Food Contact

Brand name	Material
BASF SE	
EcoflexF BX 7011	TPC
EcoflexS BX 7025	TPC
EcovioL BX 8145	TPC+PLA
Biomer	
Biomer P209	PHB
BIOTEC	
Bioplast GS 2189	PSAC
Bioplast TPS	PSAC
FKuR	
Bio-Flex F 2110	PLA+TPC
Biograde C 9550	CA
Innovia Films Ltd.	
CelloTherm P400	CH
CelloTherm T335	CH
CelloTherm T430	CH
NatureFlex 120NE	CH

Table 5.3 Biopolymers Approved for Applications with Food Contact (continued)

Brand name	Material
NatureFlex 165NE	CH
NatureFlex 19NE30	CH
NatureFlex 23NE30	CH
NatureFlex 23NE30 White	CH
NatureFlex 23NM	CH
NatureFlex 30NE30	CH
NatureFlex 42NE30	CH
NatureFlex 75NE	CH
NatureFlex 90NE	CH
NatureFlex NVR (E971)	CH
NatureFlex NVS	CH
Kareline natural composites	
Kareline PLM S5050	PLA-WO
NatureWorks	
PLA Polymer 2002D	PLA
PLA Polymer 3001D	PLA
PLA Polymer 3051D	PLA
PLA Polymer 3251D	PLA
PLA Polymer 4032D	PLA
PLA Polymer 4042D	PLA
PLA Polymer 4050D	PLA
PLA Polymer 4060D	PLA
PLA Polymer 7000D	PLA
PLA Polymer 7032D	PLA
PLA Polymer 8251D	PLA
PLA Polymer 8302D	PLA

Table 5.3 Biopolymers Approved for Applications with Food Contact (continued)

Brand name	Material
PLA Polymer 5051D	PLA
PLA Polymer 6060D	PLA
PLA Polymer 6201D	PLA
PLA Polymer 6202D	PLA
PLA Polymer 6204D	PLA
PLA Polymer 6251D	PLA
PLA Polymer 6302D	PLA
PLA Polymer 6350D	PLA
PLA Polymer 6400D	PLA
PLA Polymer 6751D	PLA
Plantic	
Plantic R1	PSAC
PURAC	
PURAC CL, LM, BF, FCC	PLA
Showa Highpolymer Co., Ltd.	
Bionolle PBSA #3001	PBSA
Telles	
Mirel P1001	PHB
Mirel P1002	PHB
Mirel P2001	PHB
Tianan Biologic Materials Co	
Y1000P	PHBHV

5.2.2.2 Certification of Compostability

For biopolymer materials used in packaging, certification of compostability is very important, because various laws regarding waste disposal impose different levels of waste disposal fees on packaging materials depending on their compostability (see Chapter 3).

Table 5.4 provides an overview of those biopolymers certified as compostable according to their manufacturers. Further details regarding these biopolymer materials certified as compostable can also be found in the appendix, as well as in the biopolymer database.

Table 5.4 Biopolymers Compostability Certification (X indicates that a maximum wall thickness has been determined up to which a material was certified compostable, although this value has not been specified)

Brand name	Material	Compostable to a wall thickness of:
BASF SE		
Ecoflex Batch AB 1	TPC	X
Ecoflex Batch AB 2	TPC	X
Ecoflex Batch AB 3	TPC	X
Ecoflex Batch SL 1	TPC	X
Ecoflex Batch SL 2	TPC	X
Ecoflex C Batch Black	TPC	X
Ecoflex C Batch White	TPC	X
Ecoflex F BX 7011	TPC	X
Ecoflex S BX 7025	TPC	X
EcovioL BX 45 T	TPC+PLA	X
Ecovio L BX 8145	TPC+PLA	X
Cardia Bioplastics		
B-F	PSAC	X
B-M	PSAC	X
B-MT01	PSAC	X
BIOP Biopolymer Technologies		
BIOPAR E6104	PSAC+TPC	X
BIOPAR FG L 1701	PSAC+TPC	X
BIOPAR FG L 2801	PSAC+TPC	X
BIOPAR FG ML 1007	PSAC+TPC	X
BIOPAR FG ML 2027	PSAC+TPC	X

Table 5.4 Biopolymers Compostability Certification (X indicates that a maximum wall thickness has been determined up to which a material was certified compostable, although this value has not been specified) (continued)

Brand name	Material	Compostable to a wall thickness of:
BIOPAR FG MO 1021	PSAC+TPC	X
BIOPAR MFS	PSAC+TPC	X
Biopearls		
Biopearls M106	PLA	X
Biopearls M110	PLA	X
BIOTEC		
Bioplast GF 105	PSAC	X
Bioplast GF 106/02	PSAC	X
Bioplast GS 2189	PSAC	X
Bioplast TPS	PSAC	X
Bioplast Wrap 100	PSAC+TPC	X
Cereplast		
CP-EXC-4001	PSAC	X
CP-INJ-01N	PSAC	X
CP-INJ-06	PSAC	X
CP-INJ-1001EZC	PSAC	X
CP-INJ-13	PSAC	X
CP-TH-01A	PSAC	X
CP-TH-15000A	PSAC	X
CP-TH-6000	PSAC	X
DuPont		
Biomax TPS2001	PSAC	X
Pro-Cote Soy Polymers	SOY	X
Sorona EP	PTT	X