

Biodegradable polymer blend and method for its preparation

Field of the invention

The technical solution is related to biologically degradable polymer blends and method for their preparation. The present invention solves composition and method for preparation of the blend in such a way as to achieve better mechanical properties.

Description of the prior art

An interest in biodegradable polymers, mainly from renewable sources, is steadily increasing especially for two reasons: Ecological connections with their applications, in particularly in agriculture and packaging industries, but also awareness of exhaustibility of oil reserves. Bacterial polymers, polyhydroxyalkanoates (PHA), are an important class of the polymers, mainly poly(3-hydroxybutyrate) and its copolymers. In addition, use of primarily polylactic acid, or more precisely, polylactide in all forms and combinations of optically active isomers of lactic acid that is produced from agricultural products, and is easily biodegradable has grown in recent years. Lactide is the cyclic dimer prepared from lactic acid produced by fermentation of starch or sugar from different sources (L. Yu et al./Prog. Polym. Sci. 31, 576–602; 2006). PLA is polymer known for many years, but not till technologies for preparation of its monomer from agricultural raw materials had improved its economics. And today it is in the forefront of rapid development of the biodegradable plastic industry (Y. Tokiwa et al., Int. J. Mol. Sci., 10, 3722-3742; 2009).

A special class of polyesters, named polyhydroxyalkanoates (PHAs) is naturally produced by a wide range of microorganisms for which the polyesters serve as a source of carbon and energy. Poly- β -hydroxybutyrate (PHB), as the polymer from the PHA group, was studied in the scientific literature (as early as the last century) rather as a curiosity. However, only in relation to ecological aspects of production and applications of plastics, the research has been oriented towards commercialisation of PBHs, especially P3HB and some other polyhydroxyalkanoates, mainly copolymers of PHBHx, most often PHBHV and P3HB4HB. Fragility of PHB has been solved by copolymerisation of β – hydroxybutyrate with β –hydroxyvalerate (EP 0052459). In spite of the fact that polyhydroxyalkanoates can be processed on common devices intended for processing thermoplastics, problems that occur during their processing limit their commercial applications. It refers to limited conditions for processing, especially for their low thermal stability and a relatively slow kinetics of crystallization. A further limiting factor for a wider usage of PHAs is their relatively high price.

Another important polymer from natural resources is starch that is a research object for its usage in technical applications for many years. A disadvantage of starch for thermoplastic processing is its degradation even below its melting point. Starch is present in parts of plants in form of semi-crystalline starch granules composed of two polymers, namely amylose and amylopectin. A natural, unmodified starch does not possess the thermoplastic character due to its thermal degradation during heating even below its melting point. Therefore, the natural starch can be used in polymer mixtures purely as a particle filler. On other hand, natural starch can be modified to produce a thermoplastic material. A modification of natural starch to the thermoplastic starch (TPS) is based on the processes transforming starch to its thermoplastic form through interaction of heat, shear stress and plasticizers. For the high hydrophilicity and sensitivity to air humidity, starch is often mixed with other, especially hydrophobic polymers. Polymeric materials containing TPS have a relatively wide application potential. They can be used for production of packaging materials for foods, films, injection moulded products and various technical moulded pieces. The key limitations for a mass application of TPS are its high sensitivity to humidity, and a low strength. For these reasons, the research in this area focuses on solving problems specific to TPS alone, namely through blending TPS with other polymers, addition of nano-fillers to starch matrix, application of various types of plasticizers, modification of the starch alone by introducing of various functional groups, by decrease in molecular weight of starch, and so on. Essentially, TPS can be prepared by two technological procedures, namely either via casting from water solutions of starch, or through plastification in hot-melt during extrusion. In case of casting from solution, a suspension composed of a mixture of starch, plasticizers and other additives is heated to produce gelatinization of starch grains, and this mass is then spilled to a flat mat, cooled, dried, and the produced TPS is granulated (Koch K. et al., Int. J. Biol. Macromol., 46, 13-19, 2010). This method is more suitable for laboratory research, however, the method used almost exclusively in the industrial scale environment, is extrusion. In case of the extrusion technology, a mechanical mixture of starch and plasticizer is most often dosed to extruder, wherein starch grains are destructed during extrusion at increased temperature, and by influence of shear stress, and this results in a continuous phase of amorphous starch. A residual water in starch together with plasticizer (the most frequently represented by diol or polyol, in generally by glycerol), interacts with starch through hydroxyl groups. In the given conditions, starch converts to melted form, and flows similarly as synthetic plastics (Moscicke L., et al., Food Res. Int., 47, 291-299, 2012). Due to suitable plasticizers, TPS can be prepared, and consequently processed using common plastic processing technologies. Water can be considered as the best plasticizer for starch, and it is followed by glycerol, ethylene glycol, sorbitol, fructose, glucose, urea and amino acids (Abdorezza M.N. et al. Food Hydrocolloid, 25, 56-60, 2011). According to (Zhang, Y., Han, J.H., J. Food. Sci., 71, E109-E118, 2006), glycerine can

be considered as the best plasticizer for starch, simultaneously usable in the technical practice.

At present state of art, there are known various biodegradable materials and materials based on renewable resources, as well as processes for their processing, wherein final materials are often produced from a mixture of polymeric components with an adequate morphology that is given by distribution of the components, their dispersion and their interaction. The polymer blends are physical or mechanical mixtures of two or multiple polymers and other additives, mainly fillers, anti-degradants, nucleation agents or other additives. Preparation of polymer blends is often the only option how to obtain a polymeric material with properties that cannot be achieved by any of the components acting alone. Polymer blends are most often applied as engineering plastics used mainly in the automotive industry, electro industry and electronics industry. They are commonly polymer blends formed from conventional polymers (polymers based on raw materials from fossil resources, in particular crude oil and natural gas). The blends based on natural polymers usually improve some application properties of their individual components, wherein the effort is to wide use of the polymers from natural sources for products with a higher added value (many applications of biomaterials in the medicine), with a perspective of use in the packaging, mainly for the special packages intended for foods. In addition to setting the utility properties of polymer blends, their processing properties must be often improved, too. All of the three above mentioned groups of biodegradable polymers - PLAs, PHAs (mainly PHB) and TPS have as polymers-alone many disadvantages limiting their application in the standard practice. PHAs, in particular PHB, are highly sensitive to thermal degradation during processing in melt, but also to hydrolytic degradation in presence of compounds containing OH groups. Authors of the article (Janigová, I. et al. Polymer degradation and stability, 77, 35-41, 2002) found that degradation of PHB is strongly accelerated in the presence of glycerine that is a more effective pro-degradant than water as it leads to much faster alcoholysis of ester bonds of the PHB chain than is the rate of hydrolysis due to the presence of water. An even more effective pro-degradant causing alcoholysis of PHB is ethylene glycol (Špitálský Z., et al. Polymer degradation and stability, 91, 856 -861, 2006). TPS, PLAs and PHB as the biodegradable polymers from renewable natural resources are predetermined for the use in manufacturing ecologically acceptable plastic materials with excellent application properties, however, on the other side, these polymers alone are fragile, with a marginal elongation, and this represents a limitation for their potential applications. PLA and PHB are highly brittle and strength polymers, and so production of flexible products, in particular thin packaging films is problematic. TPS alone is fragile and very sensitive to ambient relative humidity. In addition, PLA and PHA including PHB are far more expensive in comparison to synthetic polymers. On the contrary, TPS is costly acceptable. From the point of view of the mechanical properties, their brittleness is the most serious disadvantage in all the three polymers. Many procedures related to improvement of PHB toughness were published. The most effective procedures include copolymerisation of β -hydroxybutyrate with β -hydroxyvalerate (Holmes et al./ EP 0052459; 1982), or with other, higher homologues of polyhydroxyalkanoates. However, this procedure leads to a relatively large increase in material price (Organ S.J., Barham P.J. J. Mater. Sci. 26, 1368, 1991). Another option represents an addition of plasticizer, but the effect achieved is relatively poor. And also unsatisfactory without further modifications (Billingham N.C., Henman T.J., Holmes P.A. Development in Polymer Degradation 7, chapter 7, Elsevier Sci publ., 1987). The theoretical study of PHB/PLA blends showed that their mechanical properties are ranked somewhere between the corresponding properties of individual components. In addition, majority of these blends cannot be easily mixed with other polymers, and it is manifested by further worsening of mechanical properties (T. Yokohara and M. Yamaguchi, Eur. Polym. J. 44, 677-685; 2008). Blending of fragile PHA polymers, in particular PHB, with different types of PLA causes improvement of the processing stability for these materials in comparing with alone PHA, mainly PHB. Till now, blends of PLA and PHA are not commonly used in practice, mainly due to their limited processability and inadequate mechanical properties. On the other side, the both types of polymers are perspective, and according to theoretical studies, it can be mentioned that the mixtures have a high potential for application in the special applications, such as in food packaging. Improvement of mechanical properties, especially improvement of their toughness is disclosed in the patent application (WO 2012/141660 A1) where considerable improvement of toughness for fragile PLA and PHA, mainly PHB is achieved by their combination with at least one plasticizer of the ester type in suitable concentration ratios. Further improvement of toughness for these mixtures is achieved by application of Joncryl resins. Surprisingly, combination of fragile polymers in this solution provides a tough material.

Attempts to develop ecological materials, simultaneously fulfilling the strict technical requirements for application properties, and the economic requirements to achieve an acceptable price brought development of partly or fully biodegradable polymeric compositions produced by combination of synthetic non-biodegradable or synthetic biodegradable polymers and TPS. These include mainly mixtures of TPS in combination with PE, EVOH, PCL, PBS, PBAT, PVA and other synthetic polymers, and their mutual combinations. Also, solutions according to (US 9156980 B2), (US 8889945 B2), (US 8846825 B2), (US 9327438 B2) are included.

Mixing TPS with PHA, mainly with PHB and its copolymers is problematic as polyols, most often glycerine, contained in TPS cause an intense alcoholytic degradation of the PHA chain, and a consequent abrupt decrease in viscosity of the PHA matrix, and thereby of the whole mixture. Therefore, a considerable decrease in processing stability of the mixture takes place and simultaneously also worsening mechanical properties of the final product. A negative influence of polyols, in particular glycerine and polyethylene glycol, to PHA was described in the above mentioned articles (Janigová, I et al. Polymer degradation and stability, 77, 35-41, 2002) and (Špitálský Z., et al.

Polymer degradation and stability, 91, 856 -861, 2006).

In accordance with the present state of art in the given area, the main disadvantages of blends based on biodegradable polymeric materials, in particular from renewable resources, can be identified in the following way:

1. The required processing stability of these blends, as well as their suitable mechanical properties are achieved via addition of synthetic polymers, recently mainly using PBAT, however, this decreases the whole ecological value and ecological safety of these materials.
2. Solutions leading to technically acceptable materials are economically expensive, and not satisfactorily competitive with respect to synthetic non-biodegradable as well as synthetic biodegradable materials.
3. For reasons of drop in price of the expensive ecological polymers, starch (mainly in the plasticized form) is often used as one of components, but this causes a considerable worsening the processing and mechanical properties of the materials, especially the materials containing PHA.
4. Application of TPS containing polyol as a plasticizer in the materials with present PHA leads to an abrupt decrease of the processing stability and worsening mechanical properties, and this prevents their introduction in the standard industrial practise.

Summary of the invention

The mentioned disadvantages of the ecological polymer blends known till now are solved by a blend and method for its preparation of the invention, wherein polymer components are represented by biodegradable polymers obtained or produced of raw materials from renewable sources, but with continuing use of PLA/PHA mixture, preferably a tough mixture according to (WO 2012/141660 A1), with an addition of TPS and modifier, wherein TPS is produced directly during blending with PLA, and its drying is not required prior to blending with PHA. TPS is effectively dispersed in the matrix of biodegradable polymers. A blend of PLA/PHA/TPS is produced with a good processing stability and good mechanical properties. Surprisingly, the produced homogenous blend of the invention, containing simultaneously PHA and TPS, has better mechanical properties. The required effect can be achieved only in the case that the PLA/PHA/TPS blend contains also a suitable modifier, and is prepared according to the procedure where the modifier is added to a blend with starch and PLA, prior to addition of PHA to this blend. Despite the generally known fact that plasticisers for TPS, based on the substances containing the OH groups (in particular glycerol, and other organic substances containing the OH groups), cause a strong degradation of PHA, and in this way, they worsen mechanical properties of PHA, a solution of the invention surprisingly allows to prepare a homogenous blend containing simultaneously PHA and TPS plasticized by a substances including the OH groups, wherein the final material, prepared according to the invention, shows improved mechanical properties.

Blends according to the invention are characterized by having a better tensile strength at break and/or a better relative elongation at break. The invention is aimed at preparing a homogenous biodegradable polymer blend with improved mechanical properties.

For purpose of the invention, individual terms in the present text shall have the following meaning:

Starch

"Starch" is to be understood as a substance deposited in plants through the process of photosynthetic assimilation, representing a mixture of amylose and amylopectin, and that can, in addition to these polymers, optionally contains also a small quantity of lipids, proteins and a limited quantity of water. For purposes of the invention, the term starch corresponds to a starch in the form obtained from plants by a mechanical way: via grinding and washing, without any other chemical or physical processing. For purposes of the invention, the term starch is to be understood as a starch produced from any plant, such as corn, potatoes, cereals, rice, amaranth, and further plants.

Component (A)

The term "component (A)" includes polymers based on lactic acid, mainly homopolymers of PLLA, PDLA, as well as copolymers thereof, or mixtures of homopolymers, mixtures of their homopolymers and copolymers, or mixtures of their copolymers, preferably PLA polymers exhibiting the relative elongation at break 10% or less, preferably 5% or less, and more preferably 3% or less, wherein determination of relative elongation at break is performed according to the methodology mentioned in description of the invention.

Component (B)

The term "component (B)" includes a thermoplastic starch (TPS), representing a mixture of starch, at least one

plasticizer from the group of substances (C), and at least one modifier from the group of substances (E) , wherein

- **group of substances (C)** includes plasticizers for starch, especially one-, two- and multiple hydroxyl groups containing alcohols and polyols, in particular glycerine, ethylene glycol, propylene glycol, diols, triols and polyols, poly-ethylene glycol, poly-propylene glycol, neopentyl glycol, further sorbitol, mannitol;

- **group of substances (E)** includes modifiers, in particular saturated or unsaturated carboxylic, dicarboxylic, tricarboxylic or polycarboxylic acids, saturated or unsaturated anhydrides, dianhydrides and polyanhydrides, and mixed anhydrides of carboxylic acids, substances containing the isocyanate groups, preferably diisocyanates, substances containing epoxide groups, halogenides of the carboxylic acids, acylimidazoles, acylphosphates, tioesters of acids, or combination thereof.

Component (D)

The term "component (D)" includes homopolymers or copolymers of polyhydroxyalkanoates (PHA), and/or their mixtures, but preferably homopolymers or copolymers based on PHB, and/or their mixtures, but more preferably homopolymers or copolymers based on P3HB, and/or their mixtures, and the most preferably if copolymers based on P3HB are copolymers of P3HB4HB, preferably the PHA homopolymers or copolymers with the value of relative elongation 10% or below, preferably 5% or below, more preferably 3% or below, wherein determination of the relative elongation at break is performed according to the methodology mentioned in description of the invention.

Component (F)

The term "component (F)" includes plasticizers for PLA and/or for PHA, preferably esters and low viscosity polyesters, mainly esters or low viscosity polyesters of citric acid, esters or low viscosity polyesters of glycerine, esters or low viscosity polyesters of diols and polyols, esters or low viscosity polyesters of phosphoric acid, esters or low viscosity polyesters of sebacic acid, esters or low viscosity polyesters of adipic acid, esters or low viscosity polyesters of phthalic acid, and other liquid esters or low viscosity polyesters and copolyesters, or their mixtures, wherein the viscosity of a plasticizer for PLA and/or PHA (component (F)) measured at 25°C according to the procedure mentioned in description of the invention is 20,000 mPas or below, preferably 5,000 mPas or below, and more preferably 3,000 mPas or below.

Group of substances (G)

The term "group of substances (G)" includes additives for modification of the processing and/or application properties of blends, wherein the group of substances (G) includes mainly inorganic or organic fillers, compatibilizers and interphase agents, pigments and dyes, nucleating agents, processing aids, anti-block and slip additives, cross-linking additives, foaming agents, antistatic additives, flame retardants, antidegradants, and other additives and modifiers, including polymers and oligomers for modification of the processing and/or application properties of blends.

Blending process

The term "blending process" includes the procedure of blending at least two components of a blend in one or several blending devices designed to prepare polymer blends, wherein the blending devices can be represented by, for example, single screw extruder or twin screw extruder, wherein the blending process is completed once a final blend is created, that is then, after output from a last blending device, cooled and granulated, but the blend can be optionally transported to a device for making of final products, such as for example cast-extruded films.

Blending step

The term "blending step" represents a blending process in which individual components are introduced under the prescribed technological conditions, all at once or sequentially, depending whether one blending step includes one or multiple phases of the blending process. Blending step starts by introducing at least one component to a blending device, and ends by the output of a final blend or a blend of at least two prescribed components from the blending device.

Phase of blending process

The term "phase of blending process" corresponds to a time interval required for blending of the prescribed number of components of the blend, wherein one phase of the blending process starts at the moment of

introduction of the prescribed components of given blend to a blending device, and ends once the blending process is either completed or interrupted, or by input of other, at least one component of blend to a continuous blending process. Addition of at least one component to the continuous blending process is always start of the next phase of the blending process.

Extrusion step

The term "extrusion step" is the blending step performed in an extruder, preferably in a single-screw extruder, more preferably in a twin-screw extruder.

Dryblend

The term "dryblend" refers to a free-flowing powder mixture of at least two components that are physically mixed at the laboratory temperature, regardless of whether liquid substances are admixed to the mixture or not.

A subject matter of the invention includes composition and preparation of a biodegradable polymer blend based on PLA, PHA and TPS, wherein the blend contains at least 3 components: PLA (component (A)), PHA (component (D)), TPS (component (B)), and optionally plasticiser for PLA and/or PHA (component (F)), wherein TPS is based on a mixture of starch, plasticizer for starch (substance from the group (C)) and modifier (substance from the group (E)). A solution according to the invention is characterized by ability to use the most effective plasticizers for starch as plasticizer for TPS preparation, in especially alcohols and polyols, mainly glycerine, ethylene glycol, propylene glycol, diols, triols and polyols, polyethylene glycol, polypropylene glycol, neopentyl glycol, as well as sorbitol, mannitol. Further, the solution is characterized by use of such modifiers that show a high reactivity with OH groups, namely, in particular saturated or unsaturated compounds containing the isocyanate, anhydride, carboxylic or epoxy reactive groups, then halides of carboxylic acids, acyl imidazoles, acyl phosphates, thioesters from carboxylic acids, anhydrides of saturated or unsaturated carboxylic acids. Further, the solution is characterized by presence of component (B) together with component (A) in blending process prior to addition of component (D) to the blend. Use of the modifiers containing unsaturated bonds in their molecules, mainly double bond, allows further modification of the blends prepared in such a way, using for example cross-linking and/or grafting, e.g. in presence of peroxides. The solution of the invention uses the blend of PLA/PHA/plasticizer as a polymeric matrix, wherein ester or low viscosity polyester (component (F)) is a plasticizer for PLA and/or PHA. The solution of the invention includes then a blend prepared from biopolymers, and containing at least one PLA polymer (component (A)), at least one PHA polymer (component (D)) and TPS (component (B)), and characterized by improved mechanical properties, wherein TPS (component (B)) is based on a blend of starch, plasticizer (substance from the group (C)) and a reactive modifier (substance from the group (E)).

A procedure for preparation of the blend according to the invention is characterized by the following sequence: at first, TPS (component (B)) and PLA are blended, and then PHA is introduced to the blend, wherein the process can be performed as a single or multiple step blending process, preferably a single or multiple step extrusion, without need of removal of excessive water from hot-melt before blending PHA with TPS, or PHA with the TPS+PLA blend.

For reasons of the invention, if description of the invention, examples of embodiment or patent claims mention any concentration expression of the blend composition, mutual ratios of the blend components, or percentage composition of the blend, they are to be always understood as expression in weight units.

The invention discloses a biodegradable polymer blend with enhanced mechanical properties, and procedure for its preparation. The biodegradable polymer blend of the invention contains at least one component (A), at least one component (B), at least one component (D) and may contain component (F) or not. The biodegradable polymer blend of the invention relates to blend containing TPS - component (B) - wherein ratio of the other two blend components, (A) and (D), is in a wide range, wherein there are achieved improved mechanical properties represented by relative elongation at break ϵ_b and/or tensile strength σ_M , wherein relative elongation at break ϵ_b is higher than 100%, or tensile strength σ_M is higher than 15 MPa, preferably higher than 20 MPa, and more preferably higher than 25 MPa.

The blends of the invention are characterized in such a way that if they contain only components (A), (B), (D), and optionally component (G), their tensile strength σ_M is equal or higher than 15 MPa, preferably equal or higher than 20 MPa, and more preferably equal or higher than 25 MPa, wherein relative elongation at break ϵ_b is higher or equal than 2.0%. If the blends of the invention contain component (F), they have relative elongation at break ϵ_b higher or equal than 100%, wherein their tensile strength σ_M is higher or equal than 3.0 MPa, preferably is higher or equal than 5.0 MPa, preferably is higher or equal than 10 MPa.

The blends of the invention are characterized in such a way that if they have relative elongation at break ϵ_b lower than 100%, their tensile strength σ_M is equal or higher than 15 MPa, preferably equal or higher than 20 MPa, preferably equal or higher than 25 MPa.

The blends of the invention are characterized in such a way that if they have tensile strength σ_M lower than 10 MPa, preferably lower than 15 MPa, their relative elongation at break ϵ_B is equal or higher than 100%.

The mentioned effect is achieved by a such composition of the blends where ratio of the components (A) / (D) is in the range of 5/95 to 95/5, preferably of 10/90 to 90/10, more preferably of 20/80 to 80/20, even more preferably of 30/70 to 70/30.

The mentioned effect is achieved by a such quantity of starch used in the component (B) that the ratio [(A)+(D)]/(starch) is in the range of 97/3 to 40/60, preferably of 97/3 to 50/50, more preferably of 97/3 to 70/30.

Further, the mentioned effect is achieved by a such quantity of a substance from the group (C) in component (B) that the ratio of substance from the group (C) / starch is at least 5/95, preferably at least 10/90, more preferably at least 20/80, even more preferably at least 30/70, even more preferably at the most 40/60, even more preferably at the most 50/50.

Further, the mentioned effect is achieved by a such quantity of a substance from the group (E) that the ratio (E)/[starch + (C)] was at least 0.05/100, preferably at least 0.1/100, more preferably at least 0.5/100, even more preferably at least 1.1/100, even more preferably up to 10/100, even more preferably up to 5/100, and even more preferably up to 3.0/100.

Further, the mentioned effect is achieved in such a way that the blend can contains a substance from the group (F) or not. If the blend contains a substance from the group (F), then in order for the blend to achieve relative elongation at least 100, the ratio (F)/[(A) + (D)] should be at least 5/95, preferably at least 7/93, more preferably at least 10/90, even more preferably at least 15/85, even more preferably at the most 50/50, even more preferably at the most 40/60, and even more preferably at the most 30/70.

Further, a biodegradable blend of the invention can contains other substances to acquire specific, in particular the processing and application properties of the blend, specifically the substances from the group (G), such as inorganic or organic fillers, compatibilizers and interphase agents, pigments and dyes, nucleating agents, processing aids, anti-block and slip additives, crosslinking additives, foaming agents, antistatic additives, flame retarders, antidegradants, and other additives and modifiers, including polymers and oligomers.

A method for preparation a blend of the invention is characterized by using any blending device for production of polymer blends to prepare the blend, wherein production of the blend can be performed either in one or multiple blending steps, preferably in single or two steps, more preferably in one step, wherein preferably extruders are used as blending devices, more preferably single or twin screw extruders.

No matter whether the blending process consists of one or several steps, a method of the invention is characterized by presence of component (B) in the blend during at least one phase of the blending process where simultaneously at least one component (B) and one component (A) are blended, and as an option, component (F) and/or component (G) can be present. This blending phase of blending process precedes by at least one phase that blending phase of the blending process where component (D) is added to the blending process.

A method of preparation is characterized in such a way that component (D) is added to the blend by at least one blending phase afterwards, after mutual blending at least only one component (B) and at least one component (A).

A solution of the invention is also characterized by preparation of TPS - component (B) via plasticization of starch during preparation of blends, it needn't be prepared separately.

A method for preparing blends of the invention is also characterized in such a way that if one or several components (F) are added to a blend, wherein the components provide development of the mixture with increased toughness, component (F) can be added in any one or multiple phases of the blending process, and in one or several doses.

Further, a method for preparing blends of the invention is characterized in such a way that preferably another additive from the group (G), modifying properties of the final blend, can be added to a blend, wherein such substances can be added in any one or multiple phases of the blending process, and in one or several doses.

A method for preparing of the invention is also characterized by removal of excessive water from the blend by atmospheric or vacuum degassing only in last phases of the blending process, at the earliest after that phase, where at least component (A), component (B) and component (D) were already contained in the blend. A method for preparing of

the invention is also characterized in such a way that any blending device for preparation of polymer blends can be used, preferably an extruder, more preferably a single screw or twin screw extruder, and even more preferably a co-rotating twin screw extruder whose screws overlap each other. In case of a multi-step blending process, a different type of blending device can be used in every blending step.

Further, a method for preparing blends of the invention is characterized in such a way that preferably a twin screw extruder is used as a blending device, wherein the twin screw extruder is equipped besides dosing devices to a main feeding hopper, also by pumps allowing dosage liquids to hot melt along the extruder, and by side screw feeders allowing dosage of solid components of blend to hot melt of the blended mixture, and further also preferably equipped by atmospheric or vacuum degassing in a last part of the extruder, and preferably equipped also by a device for air or liquid cooling of an extruded strand, as well as by a device granulating the extruded strand. Moreover, a procedure for production of blends, designed in such a way, can be equipped (as a replacement of a granulation device) by a head and by a device for production of final products, e.g. blown or cast films, extruded opened or closed profiles, and so on.

Brief description of drawings

Fig. 1. Example of the dependence of viscosity on shear rate of the plasticiser acetylbutylcitrate, measured according to STN ISO 3219

Fig. 2 Scheme of the process for producing a polymer blend according to procedure PA in the two extrusion steps, PA1 and PA2

Fig. 3 Scheme of the process for producing a polymer blend according to procedure PB in the two extrusion steps, PB1 and PB2

Fig. 4 Scheme of the process for producing a polymer blend according to procedure PC in the two extrusion steps, PC1 and PC2

Fig. 5 Scheme of the process for producing a polymer blend according to procedure PD in a single extrusion step

Fig. 6 Scheme of the process for producing a polymer blend according to procedure PE in a single extrusion step

Fig. 7 Scheme of the process for producing a polymer blend according to procedure PF in a single extrusion step

Fig. 8 Scheme of the process for producing a polymer blend according to procedure G in the two possible alternatives, PG1 and PG2

Detailed description of the invention

The below mentioned procedures were used to determine properties of blend of the invention:

Measuring mechanical properties of blends

Mechanical properties of blends of the invention were measured according to the standard STN ISO 527 on the tensile testing device Zwick Roell equipped by a mechanical extensometer, wherein measurement was carried out at the temperature 25°C, relative air humidity (RH) 50%, and rate of cross head speed 50 mm/min. The clamping length of the testing piece was 50 mm, and the distance of extensometer grips was 30 mm. According to STN ISO 527, the parameters: relative elongation at break ε_b and tensile strength σ_M were evaluated by analysis of tensile curves.

Testing pieces for mechanical properties measurements and their preparation

To prepare testing pieces for mechanical properties measurements, films of the thickness 0.040 mm were produced of used blends by chill roll technology, specifically via extrusion of hot-melt of blend on water-cooled cylinders of the laboratory chill roll line, including the following individual devices:

- Take off unit (fy Göttfert) equipped by two consecutive water-cooled cylinders, and further by a take-off and winding units. The temperature of cooled cylinders: 20°C.

- The extruder head with a flat die of the width 70 mm, and 0.4 mm slit thickness, connected either directly to the extruder of the last extrusion step, as a replacement of granulation device, or connected to the laboratory single-screw extruder (Brabender) with 19 mm screw diameter, ratio L/D=25 and the screw compression ratio 1:2. Screw geometry: A smooth screw without mixing elements with a steady increasing diameter of the screw core. In case of the used single-screw extruder produced by the company Brabender, the processing parameters were as follow:

The hot melt temperature: 190°C

The screw revolutions: 30 rev/min

Blown films produced in this way were immediately after the production cut to tapes of 15 mm width and 100 mm length, forthwith placed to a conditioning cabinet to allow conditioning the samples for 24 hours at 25°C and 50% RH. Mechanical properties were measured immediately after the 24 hour conditioning period.

Measurement of plasticizer viscosity

The viscosity of plasticizers was measured using the coaxial-cylinder rotational viscometer - Haake rheoviscometer. Measurement was carried out at 25°C, in accordance with STN ISO 3219, wherein the viscosity value was the average value of all measurements within the shear rate range of 152 s⁻¹ to 1170 s⁻¹, as all measured fluids showed the Newtonian fluid character. An example of the dependence of viscosity on shear rate of the plasticiser acetylbutylcitrate is shown on Fig. 1.

Examples of methods for preparing biodegradable polymer blends can include the following:

Two-step or single-step alignment alternatives for preparation of blends, using twin-screw extruders, wherein the mentioned following examples are non-limiting, i.e. other alternatives of the blending process alignment are possible, too. Extruders on Figures are schematically drawn, wherein division of any extruder to zones is only illustrative, and does not represent the specific order of zones or the specific order of the blending process phases.

1. Two-extrusion preparation

Procedure PA

According to procedure PA, it is prepared a dryblend (DB_A) consisting of at least starch, at least one plasticizer from the group of substances (C), and at least one modifier from the group of substances (E), wherein, in addition to these components, the dryblend can contains other additives from the group of substances (G), or not. During the first extrusion step **PA1**, the dryblend is fed to a hopper of co-rotating twin-screw extruder together with at least one component (A). Then, using a pump, component (F) is dosed to a melted mixture, if it is necessary for final properties of the blend. After output from the extruder, the blend is cooled, and granulated without exhausting excessive water. The prepared pellets are then fed again to a hopper feeder of the twin-screw extruder during the second extrusion step **PA2** together with at least one component (D). In case of necessity, other component F can be again fed to hot-melt using a pump. At the end of extruder, excessive water is removed via a vacuum degassing zone, the mixture is cooled using air- or fluid-cooling, and granulated. Humidity of the final pellets can be (if it is necessary) adjusted by drying, and then further processed. A granulation unit can be preferably replaced by a production unit producing some final products (chill roll films, blown films, etc.), that is connected to the extruder in step PA2. Other substances from the group (G) can be added (if it is necessary) to mixture either to an extruder hopper during the first extrusion step **PA1**, or to hot-melt along the extruder using a side feeder. By the similar way, other additives from the group (G) can be dosed also in the second extrusion step **PA2**. The procedure is schematically drawn on Fig. 2.

Procedure PB

According to procedure **PB**, it is prepared a dryblend (DB_B), consisting of at least starch, at least one substance from the group (C), and at least one modifier from the group of substances (E), wherein, in addition to these components, the dryblend can contains other additives from the group of substances (G), or not. The dryblend is fed to a hopper of the co-rotating twin-screw extruder during the first extrusion step **PB1**. Then, at least one component (A) is dosed to a melted mixture using a pump, and after that, component (F) can be dosed to the hot-melt if it is necessary for final properties of blend. After output from the extruder, the produced blend is cooled and granulated without exhausting excessive water. Thereafter, the formed pellets are fed again to a hopper of the twin-screw extruder during the second extrusion step **PB2**, together with at least one component (D). If necessary, it is possible to dose again other component (F) to hot-melt in extruder, using a pump. At the end of extruder, excessive water is removed via the vacuum or atmospheric degassing zone, the blend is cooled by air or fluid, and granulated. Granulation can be omitted, and during step **PB2**, some device for production of final products can be preferably attached to the extruder as a replacement of a granulation unit. Produced final products can include chill roll films, blown films etc.) Prior to further processing, humidity of the final pellets can be (if necessary) adjusted by drying. In case of necessity, other substances from the group (G) can be dosed to hot-melt either during the first extrusion step **PB1** - to an extruder hopper, or to hot-melt along the extruder, using a side feeder. By the similar way, other additives from the group (G) can be dosed also in the second extrusion step **PB2**. The procedure is schematically drawn on Fig. 3.

Procedure PC

According to procedure **PC**, it is prepared a dryblend (DB_C), consisting of at least starch, and at least one modifier from the group or substances (E), wherein in addition to these components, the dryblend can contains other additives

from the group of substances (G), or not. The dryblend is fed to a hopper of the co-rotating twin-screw extruder during the first extrusion step **PC1**. Then, at least one plasticizer from the group (C) is dosed to hot-melt using a pump, and after that at least one component (A), and if is necessary for final properties of blend, also component (F) is then dosed to a melted mixture, using a pump.

After output from extruder, the produced blend is cooled and granulated without exhausting excessive water. Thereafter, the formed pellets are dosed again to a hopper of the twin-screw extruder during the second extrusion step **PC2**, together with at least one component (D). If necessary, it is possible to dose again other component (F) to hot-melt in extruder, using a pump. At the end of extruder, excessive water is removed via the vacuum or atmospheric degassing zone, the blend is cooled by air or fluid, and granulated. Prior to further processing, humidity of the final pellets can be (if necessary) adjusted. During step **PC2**, some unit for production of final products can be preferably attached to the extruder as a replacement of a granulation unit. Produced final products can include chill roll films, blown films etc.).

In case of necessity, other substances from the group (G) can be dosed to hot-melt either during the first extrusion step **PC1** - to an extruder hopper, or to hot-melt along the extruder, using a side feeder. By the similar way, other additives from the group (G) can be dosed during the second extrusion step **PC2**, too. The procedure is schematically drawn on Fig. 4.

Alternatively, for all the procedures, PA to PC, PHA (component (D)) can be dosed during the second extrusion step PA2 to PC2 not only to a hopper but also and/or to hot-melt, using a side feeder, prior to or after dosing the component (F) - Fig. 2-4.

2. One-extrusion preparation

Procedure PD

According to procedure **PD**, it is prepared a dryblend (DB_D) consisting of at least starch, at least one plasticizer from the group of substances (C), and at least one modifier from the group of substances (E), wherein, in addition to these components, the dryblend can contains other additives from the group (G), or not. Dryblend is fed to a hopper of the co-rotating twin-screw extruder together with at least one component (A) Then, if it is necessary for final properties of blend, component (F) is dosed to hot-melt in the extruder, using a pump, and at least one component (D) is dosed through a side feeder in the second half of the extruder, and then, in case of necessity, additives from the group of substances (G) are dosed. At the end of extruder, excessive water is removed via a vacuum or atmospheric degassing zone, the blend is cooled using air- or fluid-cooling, and granulated. Humidity of the final pellets can be (if it is necessary) adjusted by drying prior to further processing the pellets. Some device for production of final products can be preferably attached to the extruder as replacement of a granulation unit. Final products can include chill roll films, blown films, and etc.). The procedure is schematically drawn on Fig. 5.

Procedure PE

According to procedure **PE**, it is prepared a dryblend (DB_E) consisting of at least starch, at least one plasticizer from the group of substances (C), and at least one modifier from the group of substances (E), wherein, in addition to these components, the dryblend can contains other additives from the group of substances (G), or not. The dryblend is dosed to a hopper of the co-rotating twin-screw extruder, and after that, at least one component (A) is dosed. In other part of extruder, component (F) is dosed using a pump, if it is necessary for final properties of blend. In the second half of extruder, at least one component (D) is dosed through a side feeder, and then, in case of necessity, additives from the group of substances (G) are dosed. At the end of extruder, excessive water is removed via a vacuum degassing zone, the mixture is cooled using air- or fluid-cooling, and granulated. Humidity of the final pellets can be if necessary adjusted by drying prior to further processing of pellets. Some device for production of final products can be preferably attached to the extruder as a replacement of a granulation unit. Produced final products can include chill roll films, blown films etc. The procedure is schematically drawn on Fig 6.

Procedure PF

According to procedure **PF**, it is prepared a dryblend (DB_F), consisting of at least starch, and at least one modifier from the group of substances (E), wherein, in addition to these components, the dryblend can contains other additives from the group of substances (G), or not. The dryblend is fed to a hopper of the co-rotating twin-screw extruder together with at least one component (A), and after that, at least one plasticizer from the group of substances (C) is dosed to the extruder using a pump. In other part of extruder, component (F) is dosed using a pump, if it is necessary for

final properties of the blend. In the second half of extruder, at least one component (D) is dosed through a side feeder, and then, in case of necessity, additives from the group of substances (G) are dosed. At the end of extruder, excessive water is removed via a vacuum degassing zone, the blend is cooled using air- or fluid-cooling, and granulated. Prior to further processing, humidity of the final pellets can be (if necessary) adjusted by drying. As a replacement of granulation, some device for production of final products can be preferably attached to the extruder. Produced final products can include chill roll films, blown films and etc. The procedure is schematically drawn on Fig. 7.

Procedure PG

According to procedure **PG**, it is prepared a dryblend (DB_G) consisting of at least starch, at least one modifier from the group of substances (E), wherein, in addition to these components, additives from the group of substances (G) can be contained or not. The dryblend is fed to a hopper of co-rotating twin-screw extruder, and after that, at least one plasticizer from the group of substances (C) is dosed to hot-melt in extruder, and then at least one component (A) - procedure **PG1**, or at first at least one component (A), and after that, at least one plasticizer from the group of substances (C) - procedure **PG2**. In other part of extruder, plasticizer from the group of substances (F) is dosed using a pump, if is necessary for final properties of blend. In the second half of extruder, at least one component (D) is dosed through a side feeder, and then, in case of necessity, additives from the group of substances (G) are dosed. At the end of extruder, excessive water is removed via a vacuum degassing zone, the mixture is cooled using air- or fluid-cooling, and granulated. Humidity of the final pellets can be if necessary adjusted by drying prior to further processing of pellets. A granulation part can be omitted, and some production device for production of final products can preferably replace a granulation unit. Final products can include chill roll films, blown films etc. The procedure is schematically drawn on Fig 8.

There were prepared reference blends that are not within range of the invention, but they serve only for comparison of mechanical properties with the blends prepared in accordance with the invention. The reference blends of composition mentioned in Table 1 & 2 were prepared under the following conditions:

The twin-screw blending device with co-rotating screws was used as a device, and is characterized by the following parameters:

- Screw diameter 26 mm, L/D=40
- Screw revolutions: 200 rev./min
- Hot-melt temperature 180°C.
- Vacuum degassing on the last zone of the screw

An extruded blend was cooled by air and then granulated. Prepared blends were processed by chill roll technology, and films of 0.040 mm thickness were prepared by method according to description of the invention.

If TPS was prepared separately, its preparation was as follows:

Dryblend was prepared by mixing in a laboratory high speed mixer produced by company Labtech, and consisting of starch and plasticizer from the group of substances (C). This dryblend was fed to hopper feeder of twin-screw extruder, where it was processed under the following conditions:

- Screw diameter 26 mm, L/D=40
- Screw revolutions: 200 rev./min
- Hot-melt temperature 150°C.
- Vacuum degassing on the last zone of the screw
- The produced TPS was extruded as a strand, cooled by air, and then granulated.

Tab 1. Composition of reference blends without plasticizer from the group (F) and without modifier from the group (E)

No. of blend	(A):(D)	Starch:[(A)+(D)]	(C):Starch	F:[(A)+(D)]	Technological Procedure
1	80:20	30:70	30:70	0	TP1
2	40:60	30:70	30:70	0	TP1
3	5:95	30:70	30:70	0	TP1
4	95:5	30:70	30:70	0	TP2
5	80:20	30:70	30:70	0	TP2
6	40:60	30:70	30:70	0	TP2
7	5:95	30:70	30:70	0	TP2
8	95:5	30:70	30:70	0	TP3
9	80:20	30:70	30:70	0	TP3
10	40:60	30:70	30:70	0	TP3
11	5:95	30:70	30:70	0	TP3

Tab 2. Composition of reference blends with a plasticizer from the group (F) and without modifier from the group (E)

No. of blend	(A):(D)	Starch:[(A)+(D)]	(C):Starch	F:[(A)+(D)]	Technological Procedure
12	80:20	30:70	30:70	0	TP1
13	40:60	30:70	30:70	0	TP1
14	5:95	30:70	30:70	0	TP1
15	95:5	30:70	30:70	0	TP2
16	40:60	30:70	30:70	0	TP2
17	5:95	30:70	30:70	0	TP2
18	95:5	30:70	30:70	0	TP3
19	40:60	30:70	30:70	0	TP3
20	5:95	30:70	30:70	0	TP3

(A) D,L-PLA, content of D-isomer= 8% Mw= 193kDa, polydispersity coefficient D=2.18

(D) P3HB, Mw=608 kDa, polydispersity coefficient D=4.23

(F) acetyltributylcitrate

Starch - Corn Starch

(C) - glycerine

TP1 - technological procedure of preparation in one extrusion step where all components were dosed to a main hopper of the twin-screw extruder, and excessive humidity was removed using vacuum prior to output of hot-melt from the extruder. After output from the extruder, hot-melt was cooled by air and granulated.

TP2 - technological procedure where at first, during the first extrusion step, the dryblend consist of starch, water-free glycerine and PLA was blended in the twin-screw extruder in such a way that all components were fed to a main hopper of the extruder, excessive humidity was removed from hot-melt by vacuum prior to output from extruder, and the blend was cooled by air and then granulated. The pellets were fed during the second extrusion step to the main hopper together with PHB. Prior to output from extruder, hot-melt was cleared of excessive humidity via vacuum degassing, and after output from extruder, it was cooled by air and granulated.

TP3 - technological procedure where at first, during the first extrusion step, thermoplastic starch alone is prepared in a twin-screw extruder. Excessive humidity is removed by vacuum prior to output of hot-melt from the extruder, and after granulation, TPS prepared in such a way is fed during the second extrusion step, together with PLA and PHB, to a main hopper. After cooling by air, the hot-melt is granulated.

Then, the cast films of 0.04 mm thickness are prepared by chill-roll technology, according to the procedure mentioned in the invention description. The mechanical properties given in Table 3 were measured.

Tab. 3. Mechanical properties of the reference blends prepared according to Table 1 & 2.

No. of blend	(A):(D)	F:[(A)+(D)]	σ_M [MPa]	ϵ_b [%]
1	80:20	0	7.3	1.4
2	40:60	0	n/a	n/a
3	5:95	0	n/a	n/a
4	95:5	0	13.4	1.1
5	80:20	0	12.7	1.2
6	40:60	0	n/a	n/a
7	5:95	0	n/a	n/a
8	95:5	0	11.2	1.1
9	80:20	0	1.4	1.1
10	40:60	0	n/a	n/a
11	5:95	15:85	n/a	n/a
12	80:20	15:85	4.5	71
13	40:60	15:85	1.7	9
14	5:95	15:85	n/a	n/a
15	95:5	15:85	9.2	89
16	40:60	15:85	1.6	8
17	5:95	15:85	n/a	n/a
18	95:5	15:85	6.5	63
19	40:60	15:85	4	7
20	5:95	15:85	3	4

σ_M - tensile strength

ϵ_b - relative elongation at break

n/a - measurement cannot be performed as a film cannot be produced from a blend

Example 1

According to the invention, blends without component (F) are prepared in accordance with the technological procedure labelled as **PROCEDURE PA**. Composition of these blends is mentioned in Table 4, and their mechanical properties in Table 5.

The blends in the first as well as second mixing step are mixed using an extruder with the following construction parameters:

A co-rotating twin-screw extruder whose screws overlap each other
 Screw diameter 26 mm
 L/D ratio = 40,
 and blending was carried out under technological conditions as follow:
 Hot melt temperature: 190°C
 Screw revolutions (rate): 250 rev/min
 First extrusion step without degassing
 Second extrusion step with vacuum degassing on the last but one zone of extruder
 Round cross section of die die
 Cooling of hot-melt by stream of air, and the next granulation of the cooled strand by a rotation granulator
 Preparation of testing pieces, and conditions of measurement of mechanical properties are mentioned in description of the invention.

Table 4. Composition of blends without plasticizer with a modifier

No. of blend	(A):(D)	F:[(A)+(D)]	Starch:[(A)+(D)]	(C):Starch	(E):[Starch+(C)]
21	95:5	0	30:70	30:70	1,1:100
22	80:20	0	30:70	30:70	1,1:100
23	40:60	0	30:70	30:70	1,1:100
24	5:95	0	30:70	30:70	1,1:100

- (A) D,L-PLA, content of D-isomer= 8% Mw= 193kDa, polydispersity coefficient D=2.18
 (D) P3HB, Mw=608 kDa, polydispersity coefficient D=4.23
 (F) acetyltributylcitrate
 Starch - corn starch
 (C) - glycerine
 (E) - phthalic anhydride

Table 5. Mechanical properties of the blends prepared according to Table 4

No. of Blend	(A):(D)	σ_M [MPa]	ϵ_b [%]
21	95:5	48.9	3.3
22	80:20	41.7	3.4
23	40:60	41.1	2.2
24	5:95	27.5	2.1

Example 2

According to the invention, the blends mentioned in Table 8 are prepared in accordance with the technological procedure described as **PROCEDURE PB**. The technological conditions used correspond to Example 1.

Table 8. Composition of blends with a plasticizer and with a modifier

No. of Blend	(A):(D)	F:[(A)+(D)]	Starch:[(A)+(D)]	(C):Starch	(E):[Starch+(C)]
25	95:5	15:85	30:70	30:70	1.1:100
26	80:20	15:85	30:70	30:70	1.1:100
24	5:95	15:85	30:70	30:70	1.1:100

- (A) D,L-PLA, content of D-isomer= 8% Mw= 193kDa, polydispersity coefficient D=2.18
 (D) P3HB, Mw=608 kDa, polydispersity coefficient D=4.23
 (F) acetyltributylcitrate
 Starch - corn starch
 (C) - glycerine
 (E) - phthalic anhydride

Table 11 includes properties of the blends prepared according to Table 8

Table 11. Properties of the blends prepared according to Tab. 8.

No. of Blend	(A):(D)	σ_M [MPa]	ϵ_b [%]
25	95:5	22.3	304
26	80:20	22.1	316
27	5:95	26.1	105

Example 3

According to the invention, the blends mentioned in Table 13 are prepared in accordance with the technological procedure described as **PROCEDURE PC**. The technological conditions used correspond to Example 1.

Table 13. Composition of the mixtures with different content of modifier

No. of blend	(A):(D)	F:[(A)+(D)]	Starch:[(A)+(D)]	(C):Starch	(E):[Starch+(C)]
28	80:20	0	30:70	30:70	0.1:100
29	80:20	0	30:70	30:70	0.5:100
30	80:20	0	30:70	30:70	1.0:100
31	80:20	0	30:70	30:70	2.0:100
32	80:20	0	30:70	30:70	5.0:100
33	80:20	0	30:70	30:70	10.0:100
34	80:20	15:85	30:70	30:70	0.05:100
35	80:20	15:85	30:70	30:70	0.23:100
36	80:20	15:85	30:70	30:70	0.46:100
37	80:20	15:85	30:70	30:70	2.75:100
38	80:20	15:85	30:70	30:70	5.00:100
39	80:20	15:85	30:70	30:70	6.88:100
40	80:20	15:85	30:70	30:70	9.18:100

(A) D,L-PLA, content of D-isomer= 8% Mw= 193kDa, polydispersity coefficient D=2.18

(D) P3HB, Mw=608 kDa, polydispersity coefficient D=4.23

(F) acetyltributylcitrate

Starch - corn starch

(C) - glycerine

(E) - phthalic anhydride

Table 14 includes mechanical properties of the blends prepared according to Table 13.

Table 14. Mechanical properties of the blends prepared according to Tab. 13

No. of blend	(A):(D)	F:[(A)+(D)]	(E):[Starch+(C)]	σ_M [MPa]	ϵ_b [%]
28	80:20	0	0.1:100	44.0	2.2
29	80:20	0	0.5:100	45.0	2.3
30	80:20	0	1.0:100	38.4	2.5
31	80:20	0	2.0:100	41.1	2.5
32	80:20	0	5.0:100	41.8	3.1
33	80:20	0	10.0:100	36.9	3.5
34	80:20	15:85	0.05:100	10.3	110
35	80:20	15:85	0.23:100	11.6	112
36	80:20	15:85	0.46:100	13.8	159
37	80:20	15:85	2.75:100	14.7	270
38	80:20	15:85	5.00:100	12.1	255
39	80:20	15:85	6.88:100	12.1	265
40	80:20	15:85	9.18:100	12.0	253

Example 4

According to the invention, blends corresponding to Table 15 are prepared in accordance with the technological procedure mentioned as **PROCEDURE PA**. The technological conditions used correspond to Example 1, mechanical properties of the blends are mentioned in Table 16.

Table 15. Composition of blends with various content of a plasticizer from the group (F)

No. of blend	(A):(D)	F:[(A)+(D)]	Starch:[(A)+(D)]	(C):Starch	(E):[Starch+(C)]
41	80:20	15:85	30:70	5:95	1.1:100
42	80:20	15:85	30:70	10:90	1.1:100
43	80:20	15:85	30:70	15:85	1.1:100
44	80:20	15:85	30:70	20:80	1.1:100
45	80:20	15:85	30:70	30:70	1.1:100
46	80:20	15:85	30:70	50:50	1.1:100

(A) D,L-PLA, content of D-isomer= 8% Mw= 193kDa, polydispersity coefficient D=2.18

(D) P3HB, Mw=608 kDa, polydispersity coefficient D=4.23

(F) acetyltributylcitrate

Starch - corn starch

(C) - glycerine

(E) - phthalic anhydride

Table 16. Mechanical properties of the blends prepared according to Tab. 15

No. of Mixture	(C):Starch	σ_M [MPa]	ϵ_b [%]
41	5:95	10.8	196
42	10:90	13.3	215
43	15:85	17.2	250
44	20:80	15.6	257
45	30:70	23.4	299
46	50:50	14.9	337

Example 5

According to the invention, the blends corresponding to Table 17 are prepared in accordance with the technological procedure mentioned as **PROCEDURE PA**, under technological conditions corresponding to Example 1. The blends are with different types of modifiers from the group (E) according to Table 17, and their mechanical properties are listed in Table 18.

Table 17. Composition of blends with different types of modifiers from the group of substances (E)

No. of blend	Type of Modifier (E)	(A):(D)	F:[(A)+(D)]	Starch:[(A)+(D)]	(C):Starch	(E):[Starch+(C)]
47	M2	80:20	15:85	30:70	30:70	1.1:100
48	M3	80:20	15:85	30:70	30:70	1.1:100
49	M4	80:20	15:85	30:70	30:70	1.1:100
50	M5	80:20	15:85	30:70	30:70	1.1:100
51	M6	80:20	15:85	30:70	30:70	1.1:100
52	M7	80:20	15:85	30:70	30:70	1.1:100
53	M8	80:20	15:85	30:70	30:70	1.1:100
54	M9	80:20	15:85	30:70	30:70	1.1:100
55	M10	80:20	15:85	30:70	30:70	1.1:100
56	M11	80:20	15:85	30:70	30:70	1.1:100
57	M12	80:20	15:85	30:70	30:70	1.1:100
58	M13	80:20	15:85	30:70	30:70	1.1:100
59	M14	80:20	15:85	30:70	30:70	1.1:100

(A) D,L-PLA, content of D-isomer= 8% Mw= 193kDa, polydispersity coefficient D=2.18

(D) P3HB, Mw=608 kDa, polydispersity coefficient D=4.23

(F) acetyltributylcitrate

Starch - corn starch

(C) - glycerine

M2 - 1,2,3,6-Tetrahydrophthalic anhydride

M3 - Trimellitic anhydride

M4 - Maleic anhydride

M5 - Hexahydrophthalic anhydride

M6 - Toluene-2,4-diisocyanate dimer

M7 - 4,4'-Diphenylmethane diisocyanate

M8 - Epoxidized styrene and methylmethacrylate copolymer, Mw 6800g/mol, EEW*=285 g/mol

M9 - Citric anhydride

M10 - Succinic anhydride

M11 - Citric acid

M12 - Adipic acid

M13 - Hexamethylene diisocyanate

M14 - Pyromellitic dianhydride

* EEW= epoxy equivalent weight

Table 18. Mechanical properties of the blends prepared according to Tab. 17

No. of blend	Type of Modifier (E)	σ_M [MPa]	ϵ_b [%]
47	M2	10.9	251
48	M3	18.6	255
49	M4	21.0	306
50	M5	11.5	200
51	M6	11.7	189
52	M7	12.1	188
53	M8	11.4	181
54	M9	23.5	334
55	M10	17.9	303
56	M11	21.2	324
57	M12	10.1	153
58	M13	12.0	238
59	M14	20.0	322

Example 6

According to the invention, blends are prepared in accordance with the technological procedure mentioned as **PROCEDURE PA**, under technological conditions corresponding to Example 1. The blends are with different types of PLAs from the group (A) according to Table 19. Their mechanical properties are summarized in Table 20.

Table 19. Composition of blends with different types of PLAs from the group (A)

No. of blend	Type of PLAs (A)	(A):(D)	F:[(A)+(D)]	Starch:[(A)+(D)]	(C):Starch	(E):[Starch+(C)]
60	PLA 1	80:20	15:85	30:70	30:70	1.1:100
45	PLA 2	80:20	15:85	30:70	30:70	1.1:100
61	PLA 3	80:20	15:85	30:70	30:70	1.1:100
62	PLA 4	80:20	15:85	30:70	30:70	1.1:100
63	PLA 5	80:20	15:85	30:70	30:70	1.1:100
64	PLA 6	80:20	15:85	30:70	30:70	1.1:100
65	PLA 7	80:20	15:85	30:70	30:70	1.1:100
66	PLA 8	80:20	15:85	30:70	30:70	1.1:100
67	PLA 6: PLA 4 1:1	80:20	15:85	30:70	30:70	1.1:100
68	PLA 7: PLA 1 1:1	80:20	15:85	30:70	30:70	1.1:100
69	PLA 3: PLA 4 1:1	80:20	15:85	30:70	30:70	1.1:100

(D) P3HB, Mw=608 kDa, polydispersity coefficient D=4.23

(F) acetyltributylcitrate

Starch - corn starch

(C) - glycerine

(E) - phthalic anhydride (A) - type of PLA:

(A) - Type of PLA	Mw kDa	Index Polydispersity	Content of D- isomer	σ_M [MPa]	ϵ_b [%]
PLA 1	202	2.18	4.20 %	44.3	8.9
PLA 2	193	2.18	8 %	43.4	3.7
PLA 3	140	1.9	2 %	56.8	2.5
PLA 4	188	1.8	12 %	37.9	4.7
PLA 5	200	1.8	2 %	58.3	2.3
PLA 6	162	1.81	<1 %	54.8	2.2
PLA 7	187	1.95	<1 %	48.4	4.1
PLA 8	195	1.98	4 %	46.9	2.4

Note: The table summarizes mechanical properties of the films prepared according to procedure included in the invention description, the part "Testing pieces for mechanical properties measurements, and their preparation", from alone PLAs, with no additives.

Table 20. Mechanical properties of the blends prepared according to Tab. 19

No. of blend	Type of PLA (A)	σ_M [MPa]	ϵ_b [%]
60	PLA 1	16.0	276
45	PLA 2	23.4	299
61	PLA 3	16.9	291
62	PLA 4	18.8	390
63	PLA 5	19.8	338
64	PLA 6	17.3	308
65	PLA 7	18.7	328
66	PLA 8	16.1	307
67	PLA 6: PLA 4 1:1	16.4	333
68	PLA 7: PLA 1 1:1	14.2	289
69	PLA 3: PLA 4 1:1	16.2	326

Example 7

According to the invention, in accordance with the technological procedure mentioned as **PROCEDURE PA**, under technological conditions corresponding to Example 1, blends were prepared with different types of plasticizers from the group (F) according to Table 21. Their mechanical properties are listed in Table 22.

Table 21. Composition of blends with different types of plasticizer PLA from the group (F)

No. of blend	Type of Plasticizer (F)	(A):(D)	F:[(A)+(D)]	Starch:[(A)+(D)]	(C):Starch	(E):[Starch+(C)]
45	F 1	80:20	15:85	30:70	30:70	1.1:100
70	F 2	80:20	15:85	30:70	30:70	1.1:100
71	F 3	80:20	15:85	30:70	30:70	1.1:100
72	F 4	80:20	15:85	30:70	30:70	1.1:100
73	F 5	80:20	15:85	30:70	30:70	1.1:100
74	F 6	80:20	15:85	30:70	30:70	1.1:100
75	F 7	80:20	15:85	30:70	30:70	1.1:100
76	F 8	80:20	15:85	30:70	30:70	1.1:100
77	F 9	80:20	15:85	30:70	30:70	1.1:100
78	F 10	80:20	15:85	30:70	30:70	1.1:100
79	F 11	80:20	15:85	30:70	30:70	1.1:100
80	F 12	80:20	15:85	30:70	30:70	1.1:100
81	F 13	80:20	15:85	30:70	30:70	1.1:100
82	F 14	80:20	15:85	30:70	30:70	1.1:100
83	F 15	80:20	15:85	30:70	30:70	1.1:100

84	F 16	80:20	15:85	30:70	30:70	1.1:100
85	F 17	80:20	15:85	30:70	30:70	1.1:100
86	F 18	80:20	15:85	30:70	30:70	1.1:100
87	F 19	80:20	15:85	30:70	30:70	1.1:100
88	F 20	80:20	15:85	30:70	30:70	1.1:100
89	F 21	80:20	15:85	30:70	30:70	1.1:100
90	F 22	80:20	15:85	30:70	30:70	1.1:100
91	F 23	80:20	15:85	30:70	30:70	1.1:100
92	F 24	80:20	15:85	30:70	30:70	1.1:100
93	F 25	80:20	15:85	30:70	30:70	1.1:100

(A) D,L-PLA, content of D-isomer= 8% Mw= 193kDa, polydispersity coefficient D=2.18

(D) P3HB, Mw=608 kDa, polydispersity coefficient D=4.23

Starch - corn starch

(C) - glycerine

(E) - phthalic anhydride

(F) type of plasticizer for PLA and/or PHA:

(F) Plasticizer Type	Chemical Name	Viscosity at 25°C mPas
F1	Acetyltributylcitrate	33
F2	Tributylcitrate	25
F3	Tris-(2-ethylhexyl)-o-acetylcitrate	85
F4	Triacetine	16
F5	Oligoester of adipic acid	3015
F6	Oligoester of adipic acid	4082
F7	Oligoester of adipic acid	589
F8	Oligoester of adipic acid	1041
F9	Di-octyl terephthalate	64
F10	Di-octyl adipate	12
F11	Diisononyl phthalate	55
F12	Oligoester of adipic acid	19890
F13	F1/F3 60:40	45
F14	F1/F3 50:50	48
F15	F1/F3 87:13	37
F16	F1/F3 83:17	36
F17	F1/F2 67:33	29
F18	F1/F4 67:33	24
F19	F2/F3 50:50	40
F20	F2/F1/F3 50:30:20	31
F21	F2/F1 50:50	28
F22	F1/F7 67:33	140
F23	F1/F8 67:33	178
F24	F1/F5 67:33	350
F25	F1/F8 67:33	427

Table 22. Mechanical properties of the blends prepared according to Tab. 21

No. of blend	Type of Plasticizer (F)	σ_M [MPa]	ϵ_b [%]
45	F 1	23.4	299
70	F 2	16.0	304
71	F 3	16.4	302
72	F 4	10.6	215
73	F 5	16.0	335
74	F 6	17.9	365
75	F 7	19.5	198

76	F 8	15.9	249
77	F 9	16.8	198
78	F 10	10.2	168
79	F 11	24.6	183
80	F 12	18.1	178
81	F 13	27.0	356
82	F 14	16.5	352
83	F 15	23.5	346
84	F 16	17.1	308
85	F 17	26.5	250
86	F 18	24.4	284
87	F 19	20.17	302
88	F 20	24.4	284
89	F 21	20.17	302
90	F 22	22.0	306
91	F 23	17.0	322
92	F 24	18.1	337
93	F 25	17.1	334

Example 8

According to the invention, in accordance with the technological procedure mentioned as **PROCEDURE PA**, under technological conditions corresponding to Example 1, blends with different types of starch were prepared according to Table 23. Their mechanical properties are listed in Table 24.

Table 23. Composition of the blends with different types of starch

No. of blend	Type of Starch	(A):(D)	F:[(A)+(D)]	Starch:[(A)+(D)]	(C):Starch	(E):[Starch+(C)]
45	Corn	80:20	15:85	30:70	30:70	1.1:100
94	Amaranth	80:20	15:85	30:70	30:70	1.1:100
95	Potato	80:20	15:85	30:70	30:70	1.1:100

(A) D,L-PLA, content of D-isomer= 8% Mw= 193kDa, polydispersity coefficient D=2.18

(D) P3HB, Mw=608 kDa, polydispersity coefficient D=4.23

(F) acetyltributylcitrate

(C) - glycerine

(E) - phthalic anhydride

Table 24. Mechanical properties of the blends prepared according to Tab. 23

No. of blend	Type of Starch	σ_M [MPa]	ϵ_b [%]
45	Corn	23.4	299
94	Amaranth	11.9	113
95	Potato	19.4	328

Example 9

According to the invention, in accordance with the technological procedure mentioned as **PROCEDURE PA**, under technological conditions corresponding to Example 1, blends with different types of plasticizers from the group (C) were prepared according to Table 25, and their mechanical properties are listed in Table 26.

Table 25. Composition of blend with different types of plasticizers from the group (C)

No. of blend	Type of Plasticizer (C)	(A):(D)	F:[(A)+(D)]	Starch:[(A)+(D)]	(C):Starch	(E):[Starch+(C)]
45	Glycerin	80:20	15:85	30:70	30:70	1.1:100
96	PEG 300	80:20	15:85	30:70	30:70	1.1:100
97	PEG 600	80:20	15:85	30:70	30:70	1.1:100
98	PEG 1000	80:20	15:85	30:70	30:70	1.1:100
99	MPG	80:20	15:85	30:70	30:70	1.1:100

(A) D,L-PLA, content of D-isomer= 8% Mw= 193kDa, polydispersity coefficient D=2.18

(D) P3HB, Mw=608 kDa, polydispersity coefficient D=4.23

(F) acetyltributylcitrate

Starch - corn starch

(C) - glycerine

(E) - phthalic anhydride

Table 26. Mechanical properties of the blends prepared according to Tab. 25

No. of blend	Type of Plasticizer (C)	σ_M [MPa]	ϵ_b [%]
45	Glycerine	23.4	299
96	PEG 300	12.1	257
97	PEG 600	11.9	234
98	PEG 1000	13.8	211
99	MPG	10.6	244

Example 10

According to the invention, in accordance with the technological procedure mentioned as **PROCEDURE PA**, under technological conditions corresponding to Example 1, blends with different types of component (D) - PHA were prepared according to Table 27. Their mechanical properties are summarized in Table 28.

Table 27. Composition of blends with different types of component (D) - various types of PHA

No. of blend	Type of PHA (D)	(A):(D)	F:[(A)+(D)]	Starch:[(A)+(D)]	(C):Starch	(E):[Starch+(C)]
45	PHA 1	80:20	15:85	30:70	30:70	1.1:100
100	PHA 2	80:20	15:85	30:70	30:70	1.1:100
101	PHA 3	80:20	15:85	30:70	30:70	1.1:100
102	PHA 4	80:20	15:85	30:70	30:70	1.1:100
103	PHA 5	80:20	15:85	30:70	30:70	1.1:100
104	PHA 6	80:20	15:85	30:70	30:70	1.1:100
105	PHA 7	80:20	15:85	30:70	30:70	1.1:100

(A) D,L-PLA, content of D-isomer= 8% Mw= 193kDa, polydispersity coefficient D=2.18

(F) acetyltributylcitrate

Starch - corn starch

(C) - glycerine

(E) - phthalic anhydride

(D) - type of PHA:

Type of PHA (D)	PHA	Mw	D index	Co-monomer Content (%)	σ_M [MPa]	ϵ_b [%]
PHA 1	P3HB	608	4.23		14.8	1.4
PHA 2	P3HB4HV	460	4.53	3.1% 4HV	27.0	3.5
PHA 3	P3HB4HV	539	4.65	5.1% 4HV	12.3	4.8
PHA 4	P3HB	428	3.54		34.5	2.6
PHA 5	P3HB	652	5.4		34.8	2.6
PHA 6	P3HB	780	3.2		33.9	2.1
PHA 7	P3HB4HB	223	3.35	17.6% 4HB	28.7	2.3

Note: The table contains mechanical properties of the films prepared according to the procedure included in the invention description, the part "Testing pieces for mechanical properties measurements, and their preparation", from alone PLAs, with no additives.

Table 28. Mechanical properties of the blends prepared according to Tab. 27

No. of blend	Type of PHA (D)	σ_M [MPa]	ϵ_b [%]
45	PHA 1	23.4	299
100	PHA 2	19.9	287
101	PHA 3	19.0	264
102	PHA 4	18.7	302
103	PHA 5	19.2	286
104	PHA 6	20.2	298
105	PHA 7	12.3	114

Example 11

According to the invention, blends are prepared in accordance with the technological procedure mentioned as **PROCEDURE PA**, under technological conditions corresponding to Example 1. The blends with addition of nucleation agents from the group of substances (G) were prepared according to Table 29, their mechanical properties are listed in Table 30. The nucleation agents from the group of substances (G) were added according to procedure PA, to a hopper during the second extrusion step PA2.

Table 29. Composition of blends with addition of nucleation agents

No. of blend	Type and Content of Nucleation Agent (G)	(A):(D)	F:[(A)+(D)]	Starch:[(A)+(D)]	(C):Starch	(E):[Starch+(C)]
106	B, 1 %	80:20	0:100	30:70	30:70	1.1:100
107	M, 1 %	80:20	0:100	30:70	30:70	1.1:100
108	B, 1 %	40:60	0:100	30:70	30:70	1.1:100
109	M, 1 %	40:60	0:100	30:70	30:70	1.1:100
110	B, 1 %	80:20	15:85	30:70	30:70	1.1:100
111	M, 1 %	80:20	15:85	30:70	30:70	1.1:100
112	B, 1 %	40:60	15:85	30:70	30:70	1.1:100
113	M, 1 %	40:60	15:85	30:70	30:70	1.1:100

(A) D,L-PLA, content of D-isomer= 8% Mw= 193kDa, polydispersity coefficient D=2.18

(D) P3HB, Mw=608 kDa, polydispersity coefficient D=4.23

(F) acetyltributylcitrate

Starch - corn starch

(C) - glycerine

(E) - phthalic anhydride

M - Talc, substance from the group (G) as a nucleation agent

B - Boron nitride, substance from the group (G) as a nucleation agent

Table 30. Mechanical properties of the blends prepared according to Tab. 29

No. of blend	Type and Content of Nucleation Agent (G)	F:[(A)+(D)]	σ_M [MPa]	ϵ_b [%]
106	B, 1 %	0:100	29.7	2.1
107	M, 1 %	0:100	30.2	2.8
108	B, 1 %	0:100	33.8	3.7
109	M, 1 %	0:100	35.0	2.9
110	B, 1 %	15:85	18.1	275
111	M, 1 %	15:85	18.2	180
112	B, 1 %	15:85	15.1	180
113	M, 1 %	15:85	15.3	260

Example 12

According to the invention, in accordance with the technological procedure mentioned as **PROCEDURE PA**: Under technological conditions corresponding to Example 1, blends with addition of fillers according to Table 31 were prepared, and their mechanical properties are listed in Table 32. The fillers from the group (G) were added according to procedure PA to a hopper, during the second extrusion step PA2.

Table 31. Composition of blends containing fillers

No. of blend	Type and Content of Nucleation Agent (G)	(A):(D)	F:[(A)+(D)]	Starch:[(A)+(D)]	(C):Starch	(E):[Starch+(C)]
114	P1, 10 %	80:20	0:100	30:70	30:70	1,1:100
115	P2, 10 %	80:20	0:100	30:70	30:70	1,1:100
116	P1, 10 %	40:60	0:100	30:70	30:70	1,1:100
117	P2, 10 %	40:60	0:100	30:70	30:70	1,1:100
118	P1, 10 %	80:20	15:85	30:70	30:70	1,1:100
119	P2, 10 %	80:20	15:85	30:70	30:70	1,1:100
120	P1, 10 %	40:60	15:85	30:70	30:70	1,1:100
121	P2, 10 %	40:60	15:85	30:70	30:70	1,1:100

(A) D,L-PLA, content of D-isomer= 8% Mw= 193kDa, polydispersity coefficient D=2.18

(D) P3HB, Mw=608 kDa, polydispersity coefficient D=4.23

(F) acetyltributylcitrate

Starch - corn starch

(C) - glycerine

(E) - phthalic anhydride

P1 - Clay, filler from the group (G) , calculated 10wt% on the whole blend

P2 - Calcium carbonate, filler from the group (G), calculated 10wt% on the whole blend

Table 32. Mechanical properties of the blends prepared according to Tab. 29

No. of blend	Type and Content of Filler (G)	(A):(D)	F:[(A)+(D)]	σ_M [MPa]	ϵ_b [%]
114	P1, 10 %	80:20	0:100	30.6	2.9
115	P2, 10 %	80:20	0:100	29.5	2.8
116	P1, 10 %	40:60	0:100	29.3	3.2
117	P2, 10 %	40:60	0:100	48.7	3.2
118	P1, 10 %	80:20	15:85	15.1	255
119	P2, 10 %	80:20	15:85	21.3	272
120	P1, 10 %	40:60	15:85	12.5	201
121	P2, 10 %	40:60	15:85	14.6	282

Example 13

According to the invention, in accordance with the technological procedure mentioned as **PROCEDURE PA**, under technological conditions corresponding to Example 1, and technological procedure TP1 mentioned in Example 2, the blends were prepared with different content of starch according to Table 33. Mechanical properties are listed in

Table 34.

Table 33. Composition of the blends with different content of starch

No. of blend	(A):(D)	F:[(A)+(D)]	Starch:[(A)+(D)]	(C):Starch	(E):[Starch+(C)]
122	80:20	15:85	3:97	30:70	1,1:100
123	80:20	15:85	10:90	30:70	1,1:100
124	80:20	15:85	20:80	30:70	1,1:100
45	80:20	15:85	30:70	30:70	1,1:100

(A) D,L-PLA, content of D-isomer= 8% Mw= 193kDa, polydispersity coefficient D=2.18

(D) P3HB, Mw=608 kDa, polydispersity coefficient D=4.23

(F) acetyltributylcitrate

Starch - corn starch

(C) - glycerine

(E) - phthalic anhydride

Table 34. Mechanical properties of the blends prepared according to Tab. 33

No. of blend	Starch:[(A)+(D)]	(E):[Starch+(C)]	σ_M [MPa]	ϵ_b [%]
122	3:97	1,1:100	32.6	328
123	10:90	1,1:100	28.7	326
124	20:80	1,1:100	25.9	329
45	30:70	1,1:100	23.4	299

Example 14

According to the invention, in accordance with the technological procedure mentioned as **PROCEDURE PA**: under technological conditions corresponding to Example 1, the blends with different types of plasticizers from the group (F) according to Table 35 were prepared. Their mechanical properties are listed in Table 36.

Table 35. Composition of blends with various content of a plasticizer from the group (F)

No. of blend	(A):(D)	F:[(A)+(D)]	Starch:[(A)+(D)]	(C):Starch	(E):[Starch+(C)]
22	80:20	0:100	30:70	30:70	1,1:100
125	80:20	10:90	30:70	30:70	1,1:100
126	80:20	13:87	30:70	30:70	1,1:100
127	80:20	15:85	30:70	30:70	1,1:100
128	80:20	20:80	30:70	30:70	1,1:100
129	80:20	25:75	30:70	30:70	1,1:100
130	80:20	33:67	30:70	30:70	1,1:100
131	80:20	30:70	30:70	30:70	1,1:100

(A) D,L-PLA, content of D-isomer= 8% Mw= 193kDa, polydispersity coefficient D=2.18

(D) P3HB, Mw=608 kDa, polydispersity coefficient D=4.23

(F) acetyltributylcitrate, for the blend No. 131 plasticizer F14 from example 7 was used

Starch - corn starch

(C) - glycerine

(E) - phthalic anhydride

Table 36. Mechanical properties of the blends prepared according to Tab. 35

No. of blend	F:[(A)+(D)]	σ_M [MPa]	ϵ_b [%]
22	0:100	41.7	2.3
125	10:90	18.8	372
126	13:87	31.4	130
127	15:85	26.7	309
128	20:80	18.4	252
129	25:75	18.1	253
130	33:67	12.5	150
131	30:70	14.8	151

Example 15

According to the invention, in accordance with the technological procedure mentioned as **PROCEDURE PA**: under the technological conditions corresponding to Example 1, the blends according to Table 37 were prepared, wherein during the extrusion step PA2, a head for production of films, and a chill roll unit were attached directly to the twin-screw extruder. Samples for mechanical properties measurements were prepared by the chill roll technology. The mechanical properties are listed in Table 38.

Table 37. Composition of the blends with different content of starch

No. of blend	(A):(D)	F:[(A)+(D)]	Starch:[(A)+(D)]	(C):Starch	(E):[Starch+(C)]
132	80:20	15:85	40:60	30:70	1.1:100
133	80:20	15:85	50:50	30:70	1.1:100
134	80:20	15:85	50:50	30:70	1.1:100
135	80:20	15:85	50:50	30:70	1.1:100
136	80:20	15:85	60:40	30:70	1.1:100

(A) D,L-PLA, content of D-isomer= 8% Mw= 193kDa, polydispersity coefficient D=2.18

(D) P3HB, Mw=608 kDa, polydispersity coefficient D=4.23

(F) acetyltributylcitrate

Starch - corn starch

(C) - glycerine

(E) - phthalic anhydride

Table 38. Mechanical properties of the blends prepared according to Tab. 37

No. of blend	Starch:[(A)+(D)]	(C):Starch	σ_M [MPa]	ϵ_b [%]
132	40:60	30:70	21.1	346
133	50:50	30:70	12.5	302
134	50:50	25:75	13.1	301
135	50:50	20:80	11.5	184
136	60:40	30:70	3.6	235

Example 16

According to the invention, according to the technological procedure mentioned as **PROCEDURE PA**: under the technological conditions corresponding to Example 1, the blends according to Table 38 were prepared, wherein during the extrusion step PA2, a head for production of films, and a chill roll unit were attached directly to the twin-screw extruder. Samples for mechanical properties measurements were prepared by the chill roll technology. The mechanical properties are listed in Table 39.

Table 38B. Composition of blends with various content of a plasticizer from the group (F)

No. of blend	(A):(D)	F:[(A)+(D)]	Starch:[(A)+(D)]	(C):Starch	(E):[Starch+(C)]
137	80:20	7:93	40:60	30:70	1.1:100
138	60:40	7:93	40:60	30:70	1.1:100
139	80:20	7:93	40:60	30:70	1.1:100
140	60:40	7:93	40:60	30:70	1.1:100

(A) D,L-PLA, content of D-isomer= 12% Mw= 188kDa, polydispersity coefficient D=1.8

(D) P3HB, Mw=708 kDa, polydispersity coefficient D=3.2

(F) - F6 from Example 7; oligoester of adipic acid, viscosity at 25°C=4082 mPas

Starch - corn starch

(C) - glycerine

(E) - phthalic anhydride

Table 39. Mechanical properties of the blends prepared according to Tab. 38B

No. of blend	(A):(D)	F:[(A)+(D)]	σ_M [MPa]	ϵ_b [%]
137	80:20	7:93	18.1	268
138	60:40	7:93	12.0	149
139	80:20	7:93	20.2	181
140	60:40	7:93	13.3	115

Industrial applicability

A solution according to the present invention provides production of a biodegradable polymer blend consisting of thermoplastic starch and polyhydroxyalkanoate, wherein the blend has enhanced mechanical properties. The biodegradable polymer blend is ecological and cost-effective, with potential applications mainly in the agriculture and packaging industry sectors.

PATENT CLAIMS

1. A biodegradable polymer blend, **characterized in that** it contains at least one component (A), at least one component (B), and at least one component (D), wherein

- **component (A)** includes polymers based on lactic acid, mainly homopolymers of PLLA, PDLA, as well as their copolymers, or mixtures of their homopolymers, mixtures of their homopolymers and copolymers, or mixtures of their copolymers;

- **component (B)** includes thermoplastic starch (TPS), representing a mixture of starch, at least one plasticizer from the group of substances (C), and at least one modifier from the group of substances (E);

- **group of substances (C)** includes plasticizers for starch, in particular one-, two- and multiple hydroxyl groups containing alcohols and polyols, especially glycerine, ethylene glycol, propylene glycol, diols, triols and polyols, polyethylene glycol, polypropylene glycol, neopentyl glycol, sorbitol, mannitol;

- **group of substances (E)** includes modifiers, mainly saturated or unsaturated carboxylic acids, dicarboxylic acids, tricarboxylic acids or polycarboxylic acids, saturated or unsaturated anhydrides, and mixed anhydrides of carboxylic acids, substances containing isocyanate groups, preferably diisocyanates, substances containing epoxide groups, acyl halides, acyl imidazoles, acylphosphates, thioesters of acids, or a combination thereof;

- **component (D)** includes homopolymers or copolymers of polyhydroxyalkanoates (PHAs), and/or their mixtures, wherein they are preferably homopolymers or copolymers based on PHB and/or their mixtures;

and the biodegradable blend can optionally contain component (F), wherein

- **component (F)** includes plasticizers for PLA and/or for PHA, preferably esters and low-viscosity polyesters, in particular esters or low viscosity esters of citric acid, esters or low viscosity esters of glycerine, esters or low viscosity esters of diols and polyols, esters or low viscosity esters of phosphoric acid, esters or low viscosity esters of sebacic acid, esters or low viscosity esters of adipic acid, esters or low viscosity esters of phthalic acid, and other liquid esters and/or low viscosity polyesters and copolyesters, or their mixtures, wherein the viscosity of the plasticizer for PLA and/or PHA, measured at 25 °C, is lower or equal to 20,000 mPas.

2. The biodegradable polymer blend of claim 1, **characterized in that** it consists of at least one component (A), at least one component (B) and at least one component (D).

3. The biodegradable polymer blend of claim 2, **characterized in that** the blend shows tensile strength σ_M equal or higher than 15 MPa, wherein relative elongation at break ϵ_b is higher or equal to 2.0%.

4. The biodegradable polymer blend of claim 1, **characterized in that** it consists of component (F), and the blend shows relative elongation at break ϵ_b higher or equal to 100%, wherein tensile strength σ_M is higher or equal to 3.0 MPa.

5. The biodegradable polymer blend of claims 1 to 4, **characterized in that** the ratio (A):(D) is from 95:5 to 5:95.

6. The biodegradable polymer blend of claims 1 to 5, **characterized in that** the quantity of starch used in component (B) shall be such that the ratio [(A)+(D)]:(starch) is from the interval 97:3 - 40:60.

7. The biodegradable polymer blend of claims 1 to 6, **characterized in that** the quantity of substance from the group (C) in component (B) shall be such that the ratio of a substance from the group (C): (starch) is at least 5:95.

8. The biodegradable polymer blend of claims 1 to 7, **characterized in that** in the component (B), the ratio of a substance from the group (E) : [(starch+substance from the group (C))] is at least 0,05:100.

9. The biodegradable polymer blend of claim 1, and of claims 4 to 8, **characterized in that** the ratio (F) : [(A)+(D)] is at least 5:95.

10. The biodegradable polymer blend of claims 1 to 9, **characterized in that** the blend preferably contains component (G) to modify processing and/or utility properties of the blend, wherein the component (G) includes mainly inorganic or organic fillers, compatibilizers and interphase agents, pigments and dyes, nucleating agents, processing aids, anti-block and slip additives, cross-linking additives, foaming agents, antistatic additives, flame retardants, antidegradants, and other additives and modifiers, including polymers and oligomers.

11. A method for preparation of the biodegradable polymer blend of claims 1 to 10, **characterized in that** the composition containing components (A), (B) and (D) is prepared in a such way that components (A) and (B) are blended, wherein component (B) is present in the blend at least in one phase of the mixing process where simultaneously at least one component (B) and at least one component (A) are blended, and this phase of the blending process precedes by at least one phase that blending phase of the blending process where component (D) is added to the blending process, and optional components (F) and (G) can be added to the blend in any one or multiple phases of the blending process, either in one or in multiple doses.

12. The method for preparation of the biodegradable polymer blend of claim 11, **characterized in that** all phases of the blending process are carried out in one blending step, preferably in one extrusion step.

13. The method for preparation of the biodegradable polymer blend of claims 11 and 12, **characterized in that** at the beginning of blending process, a dryblend is prepared by mixing at laboratory temperature, wherein the dryblend consists of starch and at least one modifier (E), and the dryblend optionally can contain one or more components (C), and together with the dryblend, also a polymer from the group (A) can be added to the blend, wherein at least one substance from the group (C) is added to the blend at latest in that phase of the blending process which precedes by at least one phase the phase of the blending process in which component (D) is added to the blend, and at least one substance from the group (A) is added to the blend in that phase of the blending process which precedes at least one phase that phase of the blending process in which component (D) is added to the blend, wherein the order of dosing substances from the group (A) and (C) is discretionary, and one or multiple components (D) are added to the blend in a such phase of the blending process, which follows by at least one phase of the blending process the phase in which are simultaneously blended: starch, at least one component (A), at least one substance from the group (C), and at least one substance from group (E); wherein components (F) and (G) can be added to the blend in any phase of the blending process; and before the output of a hot-melt from the last blending step, preferably from the last extrusion step, an excessive humidity of the blend is removed by atmospheric or vacuum degassing, and the produced blend in hot-melt form is:

- (i) cooled by liquid or gas, preferably by water or air, and granulated
- (ii) or lead to a die for producing final products or intermediates, preferably by technologies based on extrusion, and preferably for production of cast, blown or biaxially oriented films, extruded profiles and other products or intermediates based on extrusion.

14. The method for preparation of the biodegradable polymer blend of claim 13, **characterized by** a multiple step method of production, and hot-melt of the blend containing at least one component (A) and at least one component (B) without presence of component (D) is, without removal of excessive water on output from the given blend step, cooled by liquid or gas, and granulated, and the produced pellets are fed to the next blending step, wherein also a polymer from the group (D) is added to the blend together with the pellets, or the polymer from the group (D) is added to the blend at latest in the last but one blending phase of the given blending step, and the excessive humidity is removed by atmospheric or vacuum degassing before the completion of the last blending step, prior to output from the blending device, and the produced blend in a form of hot-melt is then:

- (i) cooled by liquid or gas, preferably by water or air, and granulated
- (ii) or lead to a die for producing final products or intermediates, preferably by technologies based on extrusion, and preferably for production of cast or blown or biaxially oriented films, extruded profiles and other products or intermediates based on extrusion.

15. The method for preparation of the biodegradable polymer blend of claim 14, **characterized by** production performed in a blending device, preferably extruder, and preferably in two blending steps, wherein preferably they are two extrusion steps, and hot-melt of the blend is cooled, preferably by water or air.