Biocomposites from Natural Polymers and Fibers

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Introductory paper at the Faculty of Landscape Architecture, Horticulture and Crop Production Science 2015:3

Swedish University of Agricultural Sciences

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Contents

Preface

Petro-chemical based plastic materials are being used in many applications from packaging, medical applications, automobile industries and electronics etc. However, scarcity of the petroleum resources in the future and petrochemical based plastics waste and disposal problem are a major concern to find alternative resources to produce plastics which are more sustainable and environmentally friendly. Plant based polymers are excellent alternative to synthetic polymers due to their interesting mechanical and gas barrier properties for making materials. Plant proteins and starch as well as microbial polymers are examples of biopolymers which have been in focus during recent years for their attractive functional properties for material production. Plant fibers such as hemp, jute, flax and bamboo fibers are being used in bio-based materials research to replace the synthetic fibers. Recent progress in biobased materials showed the use of one or more plant polymers or with plant fibers to produce composite materials with improved properties for packaging or automobile applications. Although, there has been tremendous progress in biobased materials production; the commercial uses of such plastics are yet to come in the future.

Cover photo: Tray made from potato protein (©Faraz Muneer 2015)

Summary

Alternative resources to petroleum resources to produce environmentally friendly and sustainable plastics and composites are discussed. Such plant based resources are abundantly available at low prices being side stream products from bioethanol and food industries. The review begins with a short introduction to plant based polymers and their potential use for making plastics. Wheat gluten proteins and starch have shown attractive functional properties which are potentially suitable for making plastics with reduced carbon foot print. The structure and function of wheat gluten and potato starch and their use in different polymer blends to produce composites with improved functional properties are also discussed. The use of natural fibers and their advantage over synthetic fibers for making composites are also examined in this review.

1. Introduction

Synthetic plastics have brought many benefits to the society with a wide range of functional properties which can be used in different applications e.g. packaging, medical instruments, automobiles and many other industrial applications. However, synthetic plastics are mainly produced from petroleum based polymers coming from fossil oil origin. The main problem is the scarcity and ultimate depletion of the fossil fuels in the future which can lead to high cost of raw materials needed for plastics production (Thompson et al., 2009). Furthermore, the use of synthetic polymers for short lived applications is simply not sustainable due to an increased disposal waste problem posing threat to the environment due to its non-biodegradable nature.

Therefore, it is important to find alternatives to synthetic polymers which are more environmental friendly and sustainable for the society. As an alternative to petroleum based polymers resources, the polymers can also be obtained from different agricultural crops/plants such as wheat, soy and corn, in the form of protein and starch (Mohanty et al., 2002). Biopolymers such as plant proteins and starch, have been used in making biobased materials showing interesting properties such as mechanical and gas barrier, to be used for packaging applications and as insulation materials (Altskär et al., 2008, Thunwall et al., 2006, Thunwall et al., 2008, Blomfeldt et al., 2011, Blomfeldt et al., 2010, Wretfors et al., 2009, Wretfors et al., 2010). This review will discuss the progress of mainly wheat protein, different starches, potato proteins and plant fiber materials produced during recent years. Furthermore, options to produce biobased composites will be targeted in this review.

2. Natural Polymers

Wheat gluten

Wheat gluten is the protein fraction of the wheat grain not soluble while washed in water and the gluten is known as one example of biobased polymers suitable for making plastics with functional properties e.g. mechanical and gas barrier. Wheat gluten is a relatively inexpensive byproduct of the starch and bioethanol industry, abundantly available and is commonly used for both wheat products and as animal feed (Olabarrieta et al., 2006). Wheat gluten proteins are mainly divided into two groups, the ethanol soluble gliadins and the ethanol insoluble glutenins. In dough or when processed and hydrated, the gliadins are responsible for intramolecular bonds and the glutenin subunits are forming both inter and intramolecular linkages (Wieser, 2007). Recent studies have shown that upon heating and processing the gliadins are also becoming a part of the polymeric network (Johansson et al., 2013).

The wheat gluten polymer composition in wheat grain is affected during the growth period by several factors such as genotype, light and temperature etc. and the composition plays an important role in baking and plastics production (Malik et al., 2013, Johansson et al., 2013). However, during plastics production, the structure of the wheat gluten polymer can be modified using chemical additive, plasticizers, heat and different processing methods (Rasheed et al., 2014, Muneer et al., 2015). The wheat gluten protein tends to form a highly crosslinked network consisting of disulphide linkages, hydrogen and irreversible isopeptide bonds at higher temperatures (Olabarrieta et al., 2006). The effect of high temperature processing of wheat gluten proteins has also been studied at secondary structure level, which showed conversion of α-helices into β-sheets and a more organized structural form at different processing conditions (Rasheed et al., 2014, Ullsten et al., 2009). The structural changes in the wheat gluten polymers and individual protein groups i.e. gliadin and glutenins have been observed at molecular and nano-scale using small angle X-ray scattering (SAXS) and wide angle X-ray scattering (WAXS) techniques (Kuktaite et al., 2012, Kuktaite et al., 2011, Rasheed et al., 2014). At different sets of conditions such as with chemical additives and plasticizers, wheat gluten and gliadins have shown hierarchical hexagonal structure positively impacting the properties of the materials (Rasheed et al., 2014, Kuktaite et al., 2011). Therefore, recent advances in structural studies of these proteins can help us to understand how modifications can be made at molecular and nano-scale levels to steer the functionality of polymers for biobased materials with improved properties.

Gliadins

The gliadins in the dough or when hydrated are the monomeric part of the wheat gluten proteins with molecular weights ranging between 28,000 to 50,000 Da. The gliadins are divided into three groups of *α/β, γ* and *ω* types on the basis of amino acids sequences, amino acid compositions and their molecular weights, however, the differences are very small within each type and difference might be based on deletion, addition or substitution of only one amino acid (Wieser, 2007). The molecular weights of *α/β* and *γ* gliadins range between 28,000-35,000 Da with distinct N and C terminals. The C-terminal contains non-repetitive sequences of the amino acids with less number of glutamine and proline compared to the N-terminal. The C-terminal domain of the *α/β* and *γ* gliadins, sometimes contain six and eight cysteine, respectively (Grosch and Wieser, 1999). The N-terminal consists of repetitive units of different amino acids such as glutamine, proline, phenylalanine and tyrosine and are unique for each type of gliadin (Wieser, 2007). The *ω*-gliadins are rich in glutamine, proline and phenylalanine with molecular weight ranging between 35,000 to 50,000 Da (Wieser, 2007, Grosch and Wieser, 1999).

Glutenins

Glutenins are in all conditions the polymeric part of the wheat gluten with molecular weight of about 500,000 to over 10 million Da (Wieser, 2007). Glutenins are one of the largest polymers existing in nature (Wrigley, 1996). The molecular weight of the glutenin polymers determines the dough properties and baking quality of the bread, the glutenins account for 20-40% of the wheat gluten proteins, and their amount in the wheat flour determines the dough strength (Wieser, 2007). Glutenins are further subdivided in to two groups' i.e. low molecular weight glutenin subunits (LMW-GS) and high molecular weight glutenin subunits (HMW-GS) (Wieser and Kieffer, 2001). The LMW-GS account for almost 20% of the gluten protein and their molecular weight and amino acid composition resembles the α/β and γ gliadins (Wieser and Kieffer, 2001, Wieser, 2007). The LMW-GS have two domains, the N and C terminal. The N terminal contains glutamine- and proline-rich repetitive units, however the C-terminal is homologous to that of α/β and γ gliadins. LMW-GS also contains 6 cysteine residues in positions homologous to α/β and γ gliadins (responsible for intrachain disulphide bonds) and also two more cysteine residues unique to LMW-GS (responsible for disulphide bonds with other gluten proteins) (Grosch and Wieser, 1999, Wieser, 2007).

The HMW-GS account for 10-12% of the gluten protein although the amount can vary due to genotypic variations (Wieser, 2007, Shewry et al., 2002). The viscoelastic properties of wheat gluten are largely attributed to the HMW-GS. Previous studies have shown that wheat varieties with different number of HMW-GS have profound effect on the viscoelastic properties of the wheat dough (Shewry et al., 2002, Payne et al., 1988).

Each HMW-GS consists of three discrete structural domains and each wheat variety has been reported to contain three to five HMW-GS which are grouped in x and y types (Wieser, 2007). In

HMW-GS the N-terminal contains 81-105 amino acids residues for x and y type subunits. and the C-terminal domain has 42 amino acids residues (Shewry et al., 2002). Both N and C terminal domains are in the form of α-helices and possess the cysteine residues to make interchain disulphide bonds, and third domain largely comprised of repetitive units forming the β-turns (Shewry et al., 2002).

Processing methods

Wheat gluten can be modified to make plastics using different processing methods such as compression molding, extrusion, injection molding and film formation.

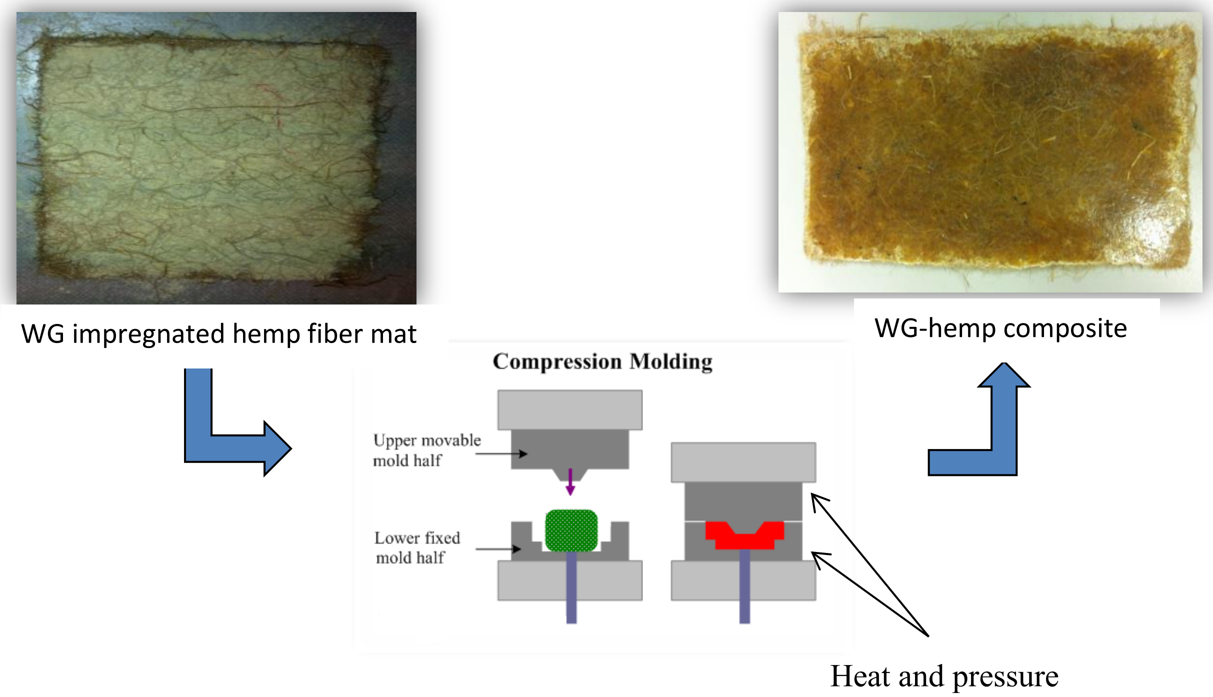

Figure 1. Hemp fiber reinforced wheat gluten composite made using compression molding method.

Compression molding is widely used and a fairly simple method where materials ready to be processed are placed between two aluminum plates using Mylar sheets and then pressed between pre-heated metal plates at controlled temperature and pressure. An example of the hemp reinforced wheat gluten plastic is given below (Figure 1).

Extrusion processing on the other hand is a complex method which is widely used in the plastics industry. In this method a pre-mixed sample is pushed through single or co-rotating screws through a tight tube where temperature, pressure and speed of the screws are controlled (Verbeek and van den Berg, 2010). During these processing technique, temperature, pressure, pH, plasticizer content and moisture affect the final properties of the material (Muneer et al., 2015). For easing the processing of protein based plastics low molecular weight plasticizers are added e.g. glycerol which lowers the glass transition temperature, improves the intermolecular forces and increases the chain mobility of the proteins hence improving the cross-linking (Di Gioia and Guilbert, 1999, Verbeek and van den Berg, 2010).

Extrusion processing also requires a complete melt of the natural polymers for a successful processing. During extrusion, proteins tend to form higher crosslinks at higher temperatures which can reduce the mobility of the molecules and increase viscosity which results in very high softening temperature even higher than the decomposition of the proteins. Another problem with extrusion of wheat gluten proteins is excessive aggregation of the proteins before exiting the extruder die which affects the mechanical properties of the materials. Such excessive aggregation of the proteins creates dense associations within the extruding materials creating several weak zones where material can break easily (Figure 2a) (Muneer et al., 2015). Therefore, to avoid such conditions, additives and plasticizers are added for a successful extrusion (Verbeek and van den Berg, 2010). Muneer et al., (2015) have reported that a careful selection of the plasticizer can have profound effect on the processing and mechanical properties of the produced material. Wheat gluten and genetically modified starch samples were extruded either with 45% glycerol or a combination of 30% glycerol and 20% water. The results clearly showed that the composites produced with combination of water and glycerol had improved processing and mechanical properties (Figure 2).

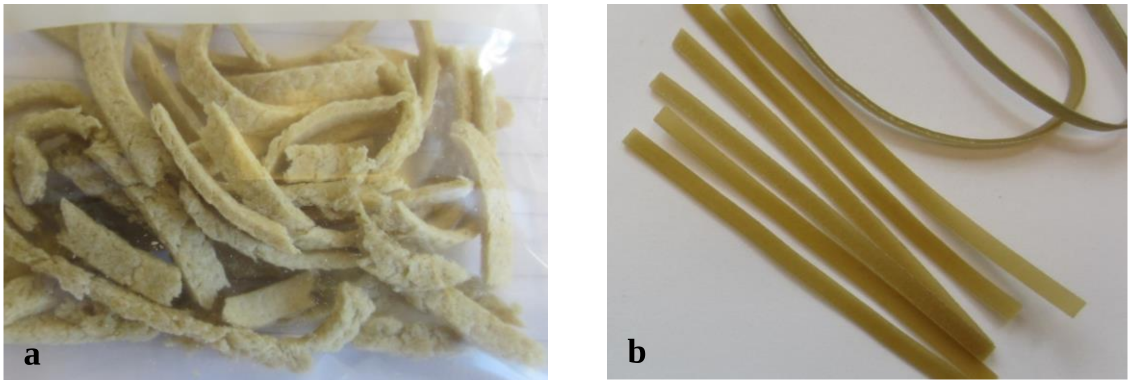

Figure 2. Wheat gluten and modified potato starch composites extruded with a) 45% glycerol and b) 30% glycerol and 20% water.

Starch

Starch is one of the main energy sources for plants to store carbohydrates and is produced in many plant storage organs as e.g. cereals, legumes and tubers in large quantities. It is abundantly available and is being used in different industrial applications such as food, textile, paper and biobased plastics etc. Starch consists of two glucose polymers with specific semi-crystalline structural arrangement; amylose with straight glucose chains arranged in 1,4 α-D-linked glucose and amylopectin with highly branched chains (Flieger et al., 2003). Normal starches are a mixture of 70-80% of amylopectin with a molecular mass of 10^8 g/mol and 20-30% amylose with a molecular mass of 10^4 to 10^8 g/mol (Van Soest and Borger, 1997). In solution, the amylose molecules tend to form more entanglements compared to amylopectin.

Starch can be obtained from different crops such as e.g. corn, wheat and potato. Starch granules show variation in size (approx. 1-100~ µm), shape (round, polygonal or lenticular) and are available in different associations as single or clusters etc. depending on the starch origin (Tester et al., 2004). For production of plastics materials, plasticizers are added followed by shear stress and temperature for the breakdown of the starch granules, and gelatinization of starch granules is desirable for improved mechanical and gas barrier properties (Muneer et al., 2015). Another successful method for a gelatinization of the starch is addition of water which acts as a destructive agent. Gelatinization results in swelling and disruption of the granular structure of the starch mainly with destruction of inter-macromolecule hydrogen bonds and a reduction in glass transition temperature (Avérous and Halley, 2009).

Potato proteins

Potato proteins concentrate (PPC) is an inexpensive co-product of the potato starch industry which is abundantly available at a price of 1.4-1.5 €/kg and an interesting source for making biobased plastics (Newson et al., 2015). In the potato starch industry, after the extraction of starch the potato fruit water (PFW) remains containing 5% dry matter of which one third is proteins, peptides and amino acids (Løkra et al., 2008). Additionally, the 5% contains potato fruit components e.g. lipids, polyphenols, organic acids, minerals and fibers, and other chemicals reagents such as $NaHSO_3$ used to prevent starch browning (Newson et al., 2015, Løkra et al., 2008). To recover the PPC from the PFW, the proteins in solution need to be coagulated for an easy recovery from the solution. For the protein coagulation the pH of the PFW is decreased to 3.5-5, and a temperature between 75-120 °C is applied followed by spray drying of the proteins (Løkra et al., 2008, Knorr, 1980).

The extracted PPC from PFW contains two types of proteins i.e. patatin (ca. 40-60%) with molecular weights between 40-43 kDa and protease inhibitors (ca. 20-50%) with molecular weight between 8-25 kDa, and other higher molecular weight (ca. 80 kDa) proteins (30-30%)

(Knorr, 1980, Løkra et al., 2008, Pots et al., 1999, Pouvreau et al., 2001). It has been reported that the recovery process of the PPC from PFW denatures the proteins and deactivates the enzymatic activity of amino acids due to the acidic and thermal coagulation (Løkra et al., 2008).

A recent study have reported the use of PPC for making biobased plastics (Newson et al., 2015). Processing conditions such as different glycerol content and temperature were used for modification of the proteins to obtain plastics with properties suitable for plastic making (Newson et al., 2015). The obtained plastics showed interesting mechanical properties which can be of interest for short lived packaging applications.

Natural fibers vs. synthetic fibers

During the last few decades, there has been a shift in materials science with a use of fiber reinforced plastics (Faruk et al., 2012, Taj et al., 2007). These fibers are mostly carbon, glass fiber and aramid reinforced with synthetic polymers to make strong composites with potential use in aerospace and automotive industry. Among these synthetic fibers, the glass fibers are most commonly used because it’s low price and good mechanical properties. However, these synthetic fibers are non-renewable, non-biodegradable, have higher cost (carbon and aramid) and are dangerous for human health during their production and even after disposal they can be dangerous for the ecosystem (Wambua et al., 2003).

There are several examples of natural fibers which are potential candidates to be used in composite plastic making e.g. jute, hemp, wheat straw, bamboo fibers, flax, banana fiber, pineapple leaf fiber, sisal and rice husk etc. (Taj et al., 2007). Natural fibers are composed of cellulose, hemicellulose, lignin and some trace amounts of waxes in some cases (Bledzki and Gassan, 1999). These natural fibers are more environmentally friendly in terms of their biodegradability, recyclability, and low energy consumption during their production and processing as compared to synthetic fibers. Therefore, during recent years the natural fibers have gained attention for their use in making composites (Wretfors et al., 2009, Reddy and Yang, 2011b).

The main advantages of using plant fibers in making biocomposites or semi-synthetic (where natural fibers are used to reinforce synthetic polymers) is their low weight and density, less abrasiveness to the machines as compared to synthetic fibers (Bledzki and Gassan, 1999). Furthermore, their CO_2 analysis has shown that the natural fibers are CO_2 neutral as they release as much as they have used consumed during their growth (Wambua et al., 2003, Bledzki and Gassan, 1999). With their recent use in the composite making the natural fibers have also shown some disadvantages such as poor adhesion to some matrices (Wretfors et al., 2009, Muneer et al., 2014). In case of poor adhesion, the matrix fails to pass on the shear stress forces to the reinforcing fibers which are supposed to strengthen the whole composite structure (Muneer et al., 2014, Wretfors et al., 2009). However, such problems can be fixed partially by treatment of the fiber surface with light alkali solution before processing which can improve fiber to matrix adhesion (Mwaikambo and Ansell, 2002).

3. Petrochemical based plastics

Petro-chemical based plastics are produced from polymers obtained as raw materials of fossil oil resources. These polymers are inexpensive and possess a wide range of properties such as light weightiness, elasticity, rigidity and with high thermal and electrical insulation. Due to their versatile nature, they are being used to make a variety of products bringing technological advances, energy saving and other benefits to the society (Thompson et al., 2009). As a result, the plastics production has increased from 0.5 million tons in 1950 to 260 million tons in 2010 and has still been increasing rapidly in recent years. Commonly used synthetic polymers for the production of plastics are polyethylene, polypropylene and polystyrene etc. which are consumed in different industrial applications (Gervet, 2007). Such large scale production of plastics was using around 4% of the oil resources of the total oil production until 2009 and is expected to increase in future (Hopewell et al., 2009). Regarding the energy consumption to produce petrochemical plastics, this has increased with over 200% until 2004 (Momani, 2009). Therefore, besides all the benefits provided by petrochemical based plastics there are several concerns for the society.

Impacts of petrochemical based plastics

Petrochemical based plastics are non-biodegradable in nature which creates a major problem of their disposal and processing which ends up in huge quantities in the environment and landfills (Thompson et al., 2009, Barnes et al., 2009). In many countries due to the lack of proper disposal facilities, these plastics end up in fresh water lakes, ponds, rivers and ultimately in the oceans affecting marine life in many ways. It has been reported that more than 260 species of birds, reptiles and mammals had been affected by these plastic physically or by the toxicity of the chemicals released in the environment (Gregory, 2009). Furthermore, the overwhelming use of petroleum resources for making plastics are also leading to higher levels of energy consumption and greenhouse gas emissions during production, contributing to global warming (Thompson et al., 2009).

Synthetic plastics polymers are processed with different additives to improve the properties and performance of the materials. Some of these are organic fillers such as silica and carbon used to improve the tensile properties, plasticizers are used to make materials pliable and coloring agents, fire retardants and weather protectants are added. A lot of these additives are toxic for humans and animals as they release from the plastics during their usage lifespan. Flame retardants, phthalate plasticizers, antimicrobial agents and bisphenol A are of major concern due to their toxic nature (Meeker et al., 2009).

Another major problem with use of plastics is CO_2 emissions during their production and processing. The chemicals and petrochemicals industries account on the top of the list of industries for consumption of energy i.e. around 30% of the total energy consumption followed by the steel industry with around 19% of the consumption. The CO_2 emission from petrochemicals, iron, steel and non-metallic (i.e. cements industries) industries accounts for 70% of the total energy consumption (Gielen et al., 2008).

4. Biobased Plastics

During the recent years, there is an increasing interest for renewable materials because of the possible limitation of oil resources, new environmental regulations in different countries, discussions about the green vs. fossil resources and limitation of waste disposal sights etc. (Domenek et al., 2004). Biobased plastics produced from natural polymers such as proteins and starch make the basis for environmentally friendly and sustainable packaging products with a potential to compete with some of the petrochemical based plastics (Mohanty et al., 2002).

Many of the commercial bioplastics are obtained from starch based polymers which are obtained from different crop such as corn, wheat, rice, potato, sorghum and barley etc. and account for almost 80% of the total biobased plastic production (Momani, 2009). The global biobased plastics production was 1.6 million tons in 2013 which is predicted to be increased up to 6.7 million tons in 2018 which will only account for 2.4% of the world's total plastic production (European plastics, 2015).

Wheat gluten based plastics

Wheat gluten proteins are of interest for making plastics due to their attractive properties such as visco-elasticity, film formation, foam formation and biodegradability (Olabarrieta et al., 2006, Blomfeldt et al., 2011). During plastic making the wheat gluten proteins are heated from 80-170°C allowing the proteins to make crosslinks which defines the properties of the materials. However, higher temperatures (more than 170°C) lead to protein breakdown or result in higher crosslinking network which negatively affect the properties (Ullsten et al., 2009). During recent years, several studies have reported the use of wheat gluten proteins for making freeze dried foams and foams with fire retardant properties (Blomfeldt et al., 2011, Blomfeldt et al., 2012, Wu et al., 2014), nano-clay reinforced composites (Kuktaite et al., 2014) and natural fiber reinforced composites (Muneer et al., 2014, Wretfors et al., 2009, Wretfors et al., 2010, Reddy and Yang, 2011a). Highly porous flame-retardant silica based wheat gluten bio-foams has shown excellent fire retardant properties which can be of interest for house insulation, sound and thermal insulations and applications where light weightiness and porosity is required (Wu et al., 2014). The nano-clay based wheat gluten films have shown interesting gas barrier properties which can potentially be explored for food packaging (Kuktaite et al., 2014). Furthermore, the hemp fibers reinforced wheat gluten sheets have shown increase in strength and stiffness properties for a potential use in packaging or other industrial applications (Muneer et al., 2014). The main gluten proteins, the gliadins and glutenins, can also be used separately for making thermoplastics films, where gliadin showed higher elongation and glutenins higher strength and stiffness (Chen et al., 2012). Furthermore, the gliadin showed their potential use as a bonding material for other biobased polymers while applying a particle bonding method (Kim, 2011).

Starch based plastics

The use of starch in plastic materials started in the 1970s with its use in synthetic plastics where it was used in small quantities as filler together with other synthetic polymers (polyethylene to starch 90:10 ratio) (Lourdin et al., 1995). Starch is a fantastic material for making biodegradable plastics with good mechanical and gas barrier properties. During processing of starch, heat, pressure, and plasticizers are applied which results in the breakdown of starch granules making it thermoplastics in nature with suitable properties for making materials (Altskär et al., 2008, Ullsten et al., 2006, Van Soest and Borger, 1997, Forssell et al., 2002). Previous studies on potato starch have shown that the starch blends with plasticizers and water can be blown into films with great potential for food packaging applications (Thunwall et al., 2008).

Starch can be either used in its original form or can be chemically and genetically modified aiming to change the structure and amount of amylose and amylopectin molecules to improve the properties of materials. Several studies have reported the improvement in mechanical properties with the use of chemically and genetically modified starches as compared to normal potato starch (Van Soest and Borger, 1997, Van Hung et al., 2006, Thunwall et al., 2006, Stagner et al., 2011, Lourdin et al., 1995). The different ratios of amylose and amylopectin content in starch granules are known to affect the properties of the final material (Van Hung et al., 2006). Thunwall et al., (2006) reported that high amylose (about 86%) potato starch based materials have improved tensile properties as compared to normal potato starch. However, the high amylose starches have higher viscosity and therefore they need much higher temperatures, shear stress and moisture content to destroy the initial crystalline structure of the granules as compared to the normal starches. More entanglements in amylose compared to amylopectin explain the higher viscosity which leads to higher tensile properties (Van Soest and Borger, 1997, Thunwall et al., 2006).

However recent study has reported an additional problem with modified potato starch where the starch granules have shown resistance to gelatinization at higher temperature, plasticizer and moisture content (Muneer et al., 2015). A combination of glycerol and water helped in partial gelatinization of the starch granules improving the mechanical properties of the material.

5. Biocomposites

Composites are composed of two or more polymers or of polymers reinforced with synthetic or natural fibers. Composites are designed with an aim to produce a material which will have a combination of the properties of the two components used during its production. The common example of composites is the synthetic polymers reinforced with synthetic fibers such as glass fibers or carbon fibers etc. where fibers provide strength and rigidity to the material. Unlike the synthetic polymers there are other examples where synthetic fibers have also been replaced with natural fibers to produce light weight composites for automotive applications (Huda and Yang, 2008b, Huda and Yang, 2008a). During recent years several efforts have been made to replace some of the synthetic composites with biodegradable composites using renewable resources. Wheat gluten and soy protein are common examples of biopolymers which have been reinforced with natural fibers such as hemp, jute and bamboo fibers to produce a biocomposite with improved mechanical properties (Muneer et al., 2014, Wretfors et al., 2009, Kunanopparat et al., 2008, Reddy and Yang, 2011a, Reddy and Yang, 2011b, Huang and Netravali, 2009). The addition of hemp fibers in wheat gluten based matrix showed an increase of 60% in the stiffness as compared to the materials without hemp fiber (Muneer et al., 2014).

Biocomposites have not only been produced by combining the natural fibers and polymers but there are several examples where two natural polymers have been combined to make a biocomposite with improved mechanical and gas barrier properties. Wheat gluten, rice proteins, egg albumin have been combined with starch with an aim to improve functional properties of the composite (Gonzalez-Gutierrez et al., 2010, Yang et al., 2011, Muneer et al., 2015). Egg albumin and potato starch based composites have shown interesting mechanical properties for packaging applications. Wheat gluten proteins have also been reinforced with nano-clay particles and have shown interesting structural properties on nano-scale and good barrier properties for packaging (Kuktaite et al., 2014). Wheat gluten and modified potato starch based extruded composites have also shown interesting gas barrier suitable for packaging industry (Muneer et al., 2015).

6. Opportunities and challenges

Plant based polymers and fibers are promising alternatives to the un-sustainable fossil based polymers and some of the synthetic fibers, as biobased polymers and fibers are important for a sustainable future with reduced waste disposal, reduced dependency on fossil resources and less greenhouse emissions. These biobased materials might have great potential for their use in packaging, automobile applications, insulations and construction industries. The importance of the biobased composite can be explained with an example from a study performed by Joshi (Joshi, 1999). According to Joshi, a car's inner door panel made from synthetic polymer weighs 27% more than a panel made from a mix of synthetic polymer and hemp fibers and similarly an insulation panel made from hemp fibers and polypropylene weighs 26% less than glass fiber reinforced material. With such kind of weight (i.e. 1 kg) a reduction in a car can help to reduce the fuel consumption by almost 6-8 liters during its lifetime (175,000 km) and reduction of CO_2 by 8-12 kg. Besides for large industrial applications, biocomposites can also be used for short term application e.g. food packaging, food coating applications and disposable cutlery etc. The production of biobased plastics was around 0.36 million metric ton in 2007 and it is expected to be around 3.45 million metric ton in 2020 (Faruk et al., 2012).

Besides having interesting properties, the biobased materials still cannot compete with synthetic plastics on commercial scale. The biobased materials are moisture sensitive which makes their use limited to less humid conditions. The mechanical properties need to be improved for their use in different kinds of applications where high strength and toughness is needed. However, with recent advancement in the biobased plastics, even a small contribution to replace the synthetic polymers can make a difference for the future.

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