Wheat Based Film

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Wheat is a grass plant of the Poaceae plants family; the scientific name of wheat plant is Triticum. Due to its mechanical and physical properties, wheat starch, gluten, and fiber are vital in the biopolymer industry. Glycerol as a plasticizer considerably increased the elongation and water vapor permeability of wheat films. Wheat fiber developed mechanical and thermal properties as a result of various matrices; wheat gluten is water insoluble, elastic, non-toxic, and biodegradable, making it useful in biocomposite materials.

wheat biocomposite | wheat starch | wheat gluten | wheat fiber | antioxidant | antimicrobial

1. Introduction

Plastic materials cause significant environmental damage and are one of humanity's greatest issues. Petroleum-based plastics are non-biodegradable, even after a hundred years. Plastic polymers, which are created from non-renewable elements, are one of the primary causes of global warming. Biocomposite materials are the ideal choice for possibly replacing fossil-based polymers. However, biocomposite materials require further development in terms of their characteristics [1].

Improving the properties of biocomposite material is still being investigated by researchers [2][3][4][5][6][7]. There is an abundance of research on wood and non-wood plants to extract starch, gluten and fiber in order to produce bio-composite materials. The ingredients of biocomposite materials are extracted from various types of agricultural crops, such as wheat, corn, cassava, hemp, jute, kenaf and other crops [8]. The advantages that make plants more useful than other sources for biopolymers are their availability, quality and quantity. In addition, plants offer variation in physical properties such as thickness, density, water content, water absorption and water solubility. There exists a variation in chemical constituents such as cellulose, hemicellulose, lignin and protein content in fiber, amylose and amylopectin ratio in starch [9]. Furthermore, their diversity in degree of polymerization, degree of crystallinity, water-vapor permeability and porosity make a difference in the biocomposite properties.

Wheat is a non-wood plants based fiber [10], which is planted in many countries and produces a lot of waste. Starch is the primary component of wheat, having a number of food and industrial applications [11]. In biocomposite application, wheat starch is used as biopolymer film with or without filler. Wheat fiber can be extracted from different parts of the plant to be used as reinforcement filler for either natural or synthesis matrix. Surface treatment is a method that is commonly used to clean, modify and improve the fiber surface to decrease surface tension and to improve the interaction between the fiber filler and the starch film matrix or synthesis matrix [12][13][14][15][16]. Several publications have addressed the effects of sodium hydroxide treatment on the structure and properties of natural fibers such as kenaf, flax, jute, hemp, sugar palm and wheat fiber [17][18][19][20][21][22].

Straws such as wheat, rice and rapeseed straws, which known as cereal straws, are not only highly abundant but they are also a low-cost, potential candidate to be utilized in the development of green composites [23]. Wheat is one of the crops that is most sought after, and it is widely cultivated. The source of it comes from a grass named (*Triticum*) that is grown in countless countries around the entire globe. The total production of wheat in 2019–2020 was 763.9 million metric tons [24] and this percentage increases yearly.

One of the co-products from the starch and bioethanol industry is wheat gluten, which is utilized in many food and non-food application. It is widely used to develop films and other Bioplastics [25][26][27][28][29]. In 36 days, the decomposition of wheat gluten takes place in aerobic fermentation and takes 50 days in farmland soil without releasing any toxic residues into the environment [30]. Wheat gluten protein has a high decomposition rate, even when it is subjected to chemical and physical treatments. Therefore, wheat gluten polymer is a perfect alternative for the development of new biodegradable polymers, because of its decomposition properties and its unique viscoelastic and gas barrier properties [31]. Furthermore, wheat gluten has been explored as a raw material for non-food applications such as biopolymers [32][33][34]. In order to develop the eco-industry on our planet, biodegradable materials such as wheat-based biocomposites, which are distinguished with unique advantages such as, renewability, availability and low-cost raw materials.

Plasticizers used with starch to create the polymeric entangled phase, by reducing intramolecular hydrogen bonding [35][36][37]. Adding plasticizer to wheat starch improves the physical and mechanical properties because plasticizer increases the flexibility of the material. There are many types of plasticizer such as, fructose, sorbitol, urea and glycerol used to improve physical and mechanical properties. Similarly, to enhance mechanical and physical properties, plasticizers have been applied in many biocomposite materials, such as corn [38][39][40], sugar palm (*Arenga pinnata*) starch [41], cassava [42] and rice starch [43][44].

2. Wheat Plant

Wheat is a grass plant of the *Poaceae* plants family; the scientific name of wheat plant is *Triticum*. Wheat is one of the world's most ancient and essential cereal crops, which is grown across a wide range of climates and types of soils [45].

The main parts of the wheat plant are head spike, stem, leaves and roots. Wheat plants grow up to 2–4 feet tall. **Figure 1** shows wheat plants' main parts. The kernel of the wheat (also called the wheat berry) is the seed of the wheat plant [46], while the part that covers the kernel and protects it is called the beard; similar to all the grass plants, wheat plants stand on the stem. The leaves of wheat plants are long and comparatively thin; flog leaves are in the top of the leaves, which are responsible for the protection of the leaves. The nourishment from the soil to the plant comes through roots in the bottom of the plant [47].

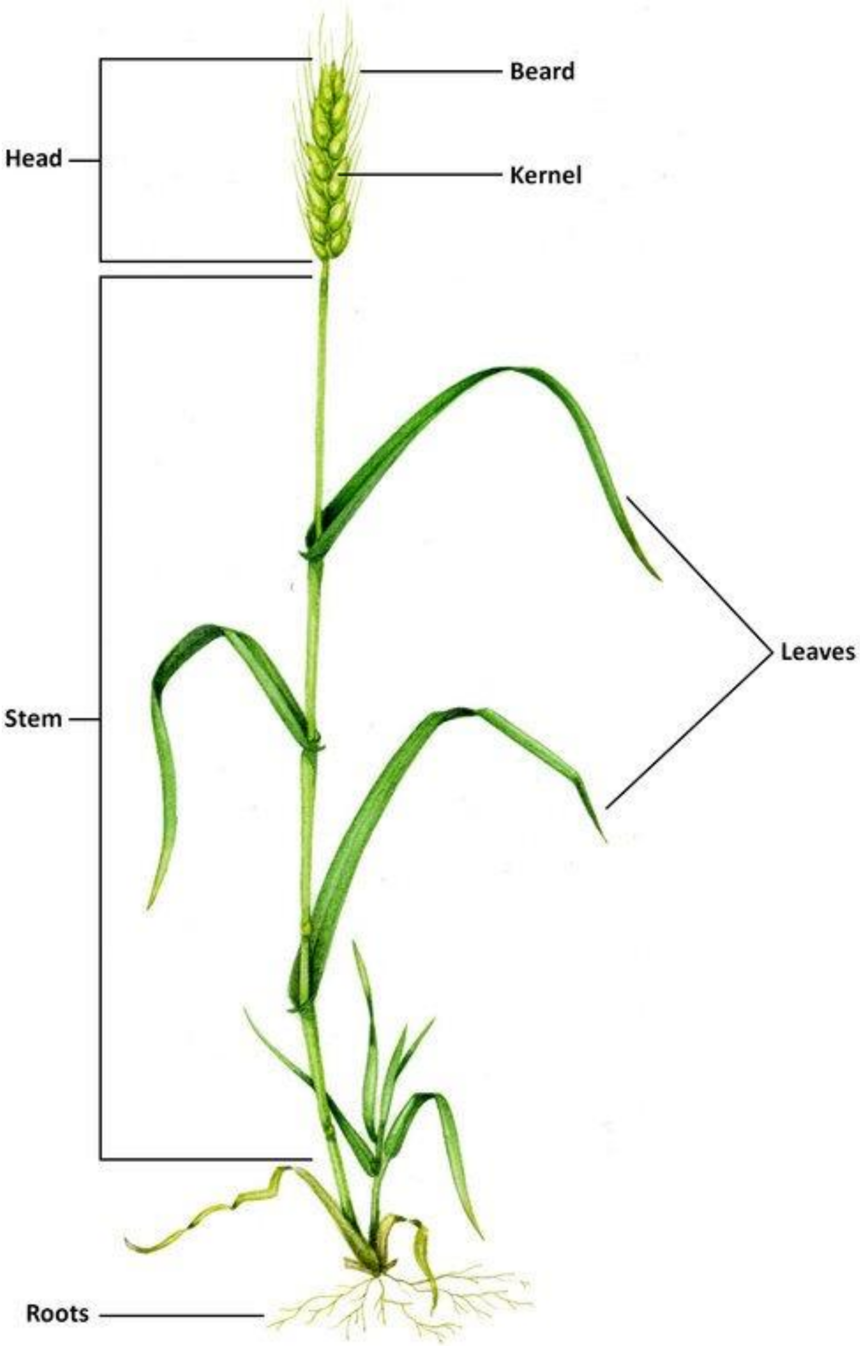

Figure 1. Wheat plant main parts [48].

3. Film Preparation and Properties Characterization of Wheat Starch Based Films

There are many factors that affect biopolymer properties, including: starch type, treatment temperature, additions such as plasticizer and co-biopolymers [35].

3.1. Physical and Chemical Properties of Wheat Starch

Wheat is one of the most widely farmed crops worldwide; the type of the soil and soil-dryness conditions affects the quality of the starch and other plant parts. The gelatinization enthalpy and swelling power of moderate soil-dryness treated starch are low. When compared to well-watered conditions, however, a greater gelatinization temperature, retrogradation enthalpy, and retrogradation percentage are found. According to Weiyang Zhang et al. [49], soil dryness affects amylose structure more than amylopectin structure in wheat grains. Furthermore, moderate soil dryness improves molecular structure and functional properties of the starch. **Table 1** shows a comparison between the chemical and physical structure of wheat, corn, rice and potato starches. There is no significant difference between the chemical composition of various starches.

The starch basically contains Amylose and Amylopectin. In biocomposite materials, it is important to identify the percentage of Amylose and Amylopectin, which directly affect the properties of the film or the matrix of the bio-polymer [50]. Amylose has a lower molecular weight than amylopectin; however, the high relative weight of Amylopectin reduces the mobility of polymer chains, resulting in high viscosity, whereas the linear structure of Amylose has demonstrated behavior more similar to that of conventional synthetic polymers [51]. The majority of natural starches are semicrystalline. Depending on the resource of the starch, the crystallinity of starch is around 20–45% percent. The short-branched chains in Amylopectin are mostly responsible for crystalline regain and appear as double helices with a length of around 5 nm. In the crystalline areas, the Amylopectin segments are all parallel to the big helix's axis [52]. Since proteins and polysaccharides are the primary components of natural polymers, the structure–property relationships in these materials are determined by their interactions with water and with each other in an aquatic medium [53].

Thianming Zhu et al. [54] applied different techniques to determine the percentage of Amylose in the starch; techniques included Differential Scanning Calorimetry (DSC), High-Performance Size-Exclusion Chromatography (HPSEC), iodine binding, and Megazyme amylose/amylopectin. Michael Ronoubigouwa Ambouroue Avaro [55] developed a method that used Tristimulus CIE Lab Values and developed a specific color board of Starch-iodine complex solution, the conversion of the regression values L*a*b* to Red, Green, Blue (RGB) values and to color hexadecimal codes. This method used a colorimeter device. A spectrophotometer is another device that can be used to detect the percentage of the Amylose by calculating the absorbent light that gets through the mixture of the starch and iodine solution [56][57][58].

Table 1. A comparison between the chemical composition and physical properties of wheat, corn, rice and potato starches [59][60][61][62][63][64][65][66][67][68][69][70][71][72].

	Type of Starch			
Parameter	Wheat Starch	Corn Starch	Rice Starch	Potato Starch
Amylose (%)	16.0–31.5	20.0–28	20–28	25–31

	Type of Starch			
Parameter	Wheat Starch	Corn Starch	Rice Starch	Potato Starch
Amylopectin (%)	68.5–75	75–83	65–85	76–83
Ash (%)	0.20–0.29	0.32–0.62	0.17–0.19	15.95–16.05
Proteins (%)	0.40–0.46	0.38–7.7	0.33–0.38	4.26–4.82
Density (g/cm^3)	1.5	1.356–1.4029	1.282	0.763
Moisture content (%)	10.65–13.3	10.45–10.82	3.60	15.98 ± 0.36

3.2. Production of Wheat Starch Based Films

In order to produce starch-based films, starch should be isolated from granules [73]; then the isolated starch is mixed with distilled water and plasticizer to prepare the slurry. Subsequently, casting and drying processes takes place.

4. Wheat Gluten-Based Film: Preparation and Characterization

Wheat Gluten (WG) is the primary protein in wheat grains [74]. Films that are made from wheat gluten have potential to develop an edible film, adhesives, binders, and biomedical substances. The main advantages of wheat gluten films include being insoluble in water, elastic in nature, and non-toxic. Gluten matrix is biodegradable and glassy, with characteristics similar to epoxy resin [75][76][77].

4.1. Production of Wheat Gluten-Based Film

Wheat-gluten-based films can be produced via two common methods:

4.1.1. Wet Method

Wet-type mechanical milling is a common approach for producing nanoparticles for a variety of bio-materials, including starch and gluten [78]. For gluten, a milling process is used to obtain gluten powder. The wheat gluten suspension solution is made by mixing the gluten powder with ethanol (70% aqueous ethanol). Then fibers are

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immersed in gluten suspension-solution. After the mixture is homogenized, the composite is dried in a vacuum air oven to allow the solvents (water and ethanol) to evaporate more quickly [79].

4.1.2. Dry Method

This method can be performed by either; (1) spreading dry powder with dry fibers in the mold, where the gluten powder will be first distributed in the mold. Next, the dry fiber preforms will be placed into the mold. Subsequently, another gluten powder layer would be added through a sieve. These steps will be repeated until the desired thickness is achieved (2), by spreading dry powder on wet fiber in the mold. In this method, fiber must be wetted again (after combing and drying), as the water will be a processing aid, after casting the gluten powder and wet fiber on the mold, the drying process needs to be conducted in dryer oven [80].

4.2. Properties Characterization of Films Based Wheat Gluten

Due to the fact that polar amino acids such as glutamic acid, aspartic acid, lysine, arginine, serine, threonine, and tyrosine are present in proteins, the addition of protein in biocomposite films improves the mechanical properties. Amino acids contain reactive groups that can be useful in cross-linking and creating covalent connections, improving the mechanical characteristics of biocomposites [81]. It has been found that proteins rich in sulfur amino acids, particularly rapeseed proteins when combined with rubber, cause a substantial enhancement of the cross-linking process. Protein-rich composites have a higher thermal resistance due to the high number of nitrogen atoms in a single polypeptide molecule [82].

Wheat gluten films revealed lower water absorption (settled on 80% after 4000 min), this amount of water absorption is a response for (C=O, C=C) bonds existence in gluten film [83]. While the starch-based films revealed higher water absorption, which reached approximately 520% after 210 min on cassava-starch-based films [42] and 295% after 240 min on corn-starch-based films [84]. All starch-based films showed very strong water absorption capacity. However, the amount of absorbed water is different from one starch to another. This behavior is attributed to the size of starch particles, the smaller the particles the earlier and higher water absorption. Also FTIR analysis shows hydrogen bonded hydroxyl group peak more intensely with small-particle content compared to the larger particles, this explains the increase in water absorption capacity [85]. Wheat-gluten-based films, plasticized with glycerol show elongation at break in the range from 320.5–471.5%, 0.03 MPa tensile strength, when the moisture content was just about 9% [86]; the addition of a plasticizer reduces hydrogen bonding, which allows molecules to move and increase the elongation, while the high tensile appears when starch-starch hydrogen bonds overcomes starch-plasticizer bonds in a low amount of plasticizer [87]. Reinforcing wheat-gluten with flax fiber improves the tensile strength and the elastic modulus, because of the hydrogen bonding between the fiber and the protein [80][88][89][90][91]. Heat treatment of wheat gluten at temperature higher than 100 °C reduces the effect of the reinforcing filler which reflected as reduction in the Young's modulus. This explains the reduction of wheat gluten adhesion when it is heat treated [92]. However, treating the filler with alkaline and/or silane improves adhesion between wheat gluten and filler. This surface treatment increases the mechanical properties by reducing the fiber pullout length [93]. As confirmed by FTIR results, fiber chemical treatment removes lignin and hemicellulose and reduces the hydrophilic nature of the fiber and, hence, improves the interfacial adhesion between fiber and matrix [94][95].

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Natural structures of bio-polymers have relatively low degradation temperatures [96]. This refers to the low energy level required to break the weak interactions between the polymer chains. To avoid undesirable decomposition of wheat gluten-based bioplastics, hydrophilic compounds, e.g., castor oil are used [97][98]. Blending wheat gluten with hydrophobic polymers, such as polyvinylalcohol improves the degradation temperature [25][99]. The addition of hydrophobic polymers widens the gap between the energy required to break bond interactions and the energy required to cause chains breakdown. Although wheat-gluten-based films also prepared with solution cast method, compression molding have given better properties [100]. The wheat-gluten films reinforced with fiber filler can be prepared either by wet or dry method:

Tensile strength increased when molding temperature increased at 35% RH, while lower values were when temperature increased at 70% RH [101]. N. Vo Hong et al. [77] used water as a processing aid together with the use of unidirectional flax fibers to obtain the strongest properties in the fiber direction. Pakanita Muensri et al. [102] found that lignin content in the fibers does not affect the fiber/matrix adhesion. The type of wheat proteins and compression molding conditions controls the properties of wheat-protein films [103]. To make edible films out of wheat gluten, Francisco Zubeldía et al. [104] employed the dry process. They observed that molding temperature has a greater impact on the films' ultimate mechanical and physical properties than mixing time. This was due to increased disulfide bonding during heating, resulting in a more cross-linked polymeric network, according to the study. Further work needs to be undertaken to understand the mechanism of cross-linking wheat gluten with fillers [105].

5. Antioxidant Properties of Wheat Based Film

The inhibition of oxidation improves the stability of polymers to be effective in more applications [106]. The addition of antioxidant into films can change the structure of the film [107], where the interaction of the antioxidant impairs the resistance to degradation [108]. Antioxidant materials are added to prolong the useful life of the constituents of polymers [74][109], the polymer type and the compound formulation and the end use application are governing the selection of the correct combination of antioxidants [110]. Wheat starch–chitosan films show the highest antioxidant (α-tocopherol) capacity. However, the addition of α-tocopherol led to more heterogeneous film structure [111]. Feruloylated arabinoxylans extracted from wheat bran show high antioxidant activity in the presence of bound ferulic acid [112].

6. Antimicrobial Properties of Wheat Based Film

Antimicrobial property has received more attention recently, especially in the bio-packaging food industry [113]. It has been found that composite wheat gluten-chitosan-based films can prevent microbial growth in intermediate-moisture conditions [114], where gluten is thought to act as an antimicrobial agents carrier [115][116][117]. Organic acids, enzymes, various plant extracts, bacteriocins, and essential oils have been integrated into biopolymers as antimicrobial agents [118][119][120]. Essential oils (EOs) used in food packaging films to inhibit the growth of bacteria and fungi [121][122][123]. Essential oils are natural, volatile, complex compounds with a strong odor extracted from

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plants [124]. They have health benefits, antimicrobial and antioxidant properties [125][126]. (EOs) used to reinforce bio-matrix composites [127], such as reinforcing corn wheat starch matrix with lemon oil, and the addition of lemon oil, significantly increased antimicrobial activity [128]. However, the addition of (EOs) concentration reduced the tensile strength, while the elongation at break does not change [129]. Potassium Sorbate (PS) has been used as an antimicrobial agent for wheat gluten films. (PS) shows antimicrobial activity, but it has been found that when the film is exposed to an absorbing medium, most of the PS is released [130]. Thymol has been added as an antimicrobial to hydroxyethyl cellulose wheat-starch-based films and the results show the film kept the same chemical properties, whereas mechanical properties improved [131].

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