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Production of biodegradable film based on pistachio protein and investigation of its physicochemical properties

Farima Aghaee[1], Nasser Sedaghat[2*], Narges Jannatiha[3], Ali Sharif[4]

1- MSc student, Department of Food Sciences and Technology, Agriculture Faculty, Ferdowsi University of Mashhad, Mashhad, Iran

2*- Professor, Department of Food Sciences and Technology, Agriculture Faculty, Ferdowsi University of Mashhad, Mashhad, Iran

3- Ph.D student, Department of Food Sciences and Technology, Agriculture Faculty, Ferdowsi University of Mashhad, Mashhad, Iran

4- Asistant Professor, Department of Food Sciences and Technology, Agriculture Faculty, Ferdowsi University of Mashhad, Mashhad, Iran

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*Corresponding Author E-

sedaghat@um.ac.ir

ABSTRACT

Pistachio meal constitutes the major part of the by-products of pistachio oil extraction (more than 60%). Pistachio meal contains compounds with nutritional value including protein, minerals and vitamins. Pistachio meal is likely to be a rich source of protein. The aim of this study was to produce biodegradable film from pistachio meal protein and the effect of glycerol treatments at three levels (0.3, 0.5 and 0.7) microscopically. The results of mechanical properties showed that with increasing glycerol concentration, tensile strength and elongation increased, while elastic modulus decreased ($P<0.05$). Increasing pH increased tensile strength, elongation, and elastic modulus ($P<0.05$). Investigation of the barrier properties of biodegradable film samples showed that increasing glycerol concentration and pH had a significant effect on permeability to oxygen and water vapor ($P<0.05$). With increasing glycerol concentration and pH, permeability to oxygen and water vapor decreased ($P<0.05$). In studying the morphology of the structure of different biodegradable films, the physicochemical properties of the samples were completely consistent with the obtained micrographs. Therefore, the optimal film based on pistachio meal protein was selected at a concentration level of 0.5 g/g protein glycerol and pH of 11.

1- INTRODUCTION

Synthetic polymers and plastics are important alternatives to glass, rubber, and metals and have a wide range of applications in various forms. Synthetic polymers can be produced very cheaply and are durable. However, the risks associated with plastic food packaging films are increasingly becoming apparent and have alarming negative impacts on human health and the environment. One of the main risks of plastic food packaging films is the release of harmful chemicals such as phthalates and bisphenol A into the packaged food. These chemicals make the plastic more flexible and durable, but they can leach out of the packaging matrix and contaminate the food inside [2, 1]. Several studies have linked exposure to these chemicals to several health problems, including developmental disorders, cancer, and endocrine disruption. Plastics, which are often single-use materials, are not recyclable and end up in landfills where they take hundreds of years to decompose. This plastic pollution seriously affects the health of the planet by harming wildlife, polluting waterways, and emitting greenhouse gases into the atmosphere. Therefore, due to the negative effects of plastic materials on the environment, it is necessary to focus more on natural polymers [4, 3]. In this context, investigating sustainable alternatives can help preserve human health and deliver a better environment to future generations. Therefore, scientists are trying to find polymeric materials that can suitably replace petroleum-based plastic food packaging films. In this regard, several biopolymer macromolecules of natural origin, such as polysaccharides and proteins, are used as ideal materials for food packaging films [6, 5]. The tendency to use biodegradable packaging is increasing day by day due to the presence of natural materials and the absence of environmental pollution in the industry [7]. Biodegradable packaging derived from agricultural products is biodegradable and is converted into natural products such as carbon dioxide, water, methane, and biomass by microorganisms during the composting process. Therefore, it does not cause environmental pollution. Edible packaging is defined as thin layers of coating or material that are incorporated into food and can be consumed without endangering human health. These packages can act as primary packaging, control the water activity of a food, regulate mass transfer in processed foods, provide a system for bioactive components, and act as sources of sensory appeal [8-10].

The increasing use of biodegradable films due to their ability to prevent the penetration of carbon dioxide, moisture, oxygen and fats and to have suitable mechanical properties has created a huge competition in the advanced field of food packaging [11]. Among the biopolymers that have attracted the attention of many researchers, the use of proteins for the development of biodegradable packages deserves to be emphasized. Given the inherent properties of proteins, they are excellent materials for preparing biodegradable packages, preventing moisture and flavor loss, controlling gas exchange and transporting active substances. In addition, protein-based packages can provide nitrogen during their own decomposition and act as fertilizers, which is a significant advantage compared to non-protein packages [7]. Plant proteins refer to a set of nutritional compounds that are of completely plant origin and are obtained from sources such as legumes (lentils, chickpeas, beans), seeds (sesame, chia, flax), nuts (almonds, walnuts, hazelnuts), whole grains (oats, brown rice, quinoa) and algae (spirulina). Plant proteins are suitable for vegan diets and offer several advantages, including diversity, economic sustainability and the presence of effective ingredients [13, 12]. Packaging produced with plant proteins in dairy products can reduce oxidation in cheese. In fruits and vegetables, they can delay the penetration of gases and water vapor and also reduce respiration. And in meat and meat products, they can delay physicochemical changes and regulate the concentration of oxygen and carbon dioxide in fresh meat to the desired level. Regarding the source of proteins, it is worth noting that the scientific community has made significant efforts to reuse by-products of the agricultural and food processing industry. This is important because it helps reduce waste, positively impact the environment, benefit the economy, and utilize scarce resources. Therefore, the use of by-products to create biodegradable and bio-based packaging is a growing trend [14]. Research has shown that about 400,000 tons of pistachio by-products are produced annually in the country. Currently, there is no specific consumption for these by-products, and the large volume during the harvest season and the high humidity of these products cause pollution of the environment and pistachio orchards. Pistachio kernels contain an average of 20% protein, which is considered a complete source of proteins among plant proteins. As a result, the biodegradable film produced from it has a suitable nutritional quality. Pistachios contain 4 simple proteins: albumin (soluble in water), globulin (soluble in dilute salt water), prolamine (soluble in 70% ethanol), and glutelin (relatively soluble in dilute acid or alkali), which account for 25, 66, 2, and 7.3% of the total protein, respectively. In this study, globulin protein was extracted to produce edible film [15, 8].

Protein-based packages usually exhibit brittleness and brittleness during thermal formation, and these characteristics lead to poor mechanical properties regarding their processability and final application. However, when natural or biodegradable plasticizers that have good compatibility with protein-based biopolymers are added, the viscoelasticity and stretchability of the packages are improved [16]. Plasticizers are an important class of low molecular weight non-volatile compounds that are widely used as additives in the polymer industry. The main role of such materials is to improve the flexibility and processability of polymers by lowering the second-order transition temperature, the glass transition temperature. Plasticizers can be inserted between polymer molecular chains and combined with polymers through physical and chemical reactions, increasing the stretchability, flexibility, elasticity, and extensibility, and reducing the cohesion and stiffness. These materials reduce the deformation stress, hardness, density, viscosity and electrostatic charge of a polymer, while increasing the flexibility of the polymer chain, fracture toughness and dielectric constant. Other properties such as crystallinity, optical transparency, electrical conductivity and resistance to biodegradation are also affected. Glycerol is almost systematically included in most films, in fact it is a highly hygroscopic molecule that is usually added to film-forming solutions to prevent film fragility [17]. Therefore, the aim of this research was to produce a biodegradable film from pistachio protein and to investigate its physicochemical properties and also to optimize the use of pistachio meal from oil extraction factories. So far, much research has been conducted on the production process and physicochemical properties of protein films, but no scientific report has been published on the physicochemical properties of pistachio meal protein films.

2- Materials and Methods

2.1. Materials

Pistachio meal (containing 4% oil), pistachio protein (with a purity of 80%) were purchased from Manila Company, Rafsanjan, sodium azide salt from Walkerman Company, Mashhad, phenylmethylsulfonyl fluoride protease inhibitor from Sigma Company, USA, trichloroacetic acid, soda and glycerol from Merck Company, Germany. Pistachio protein was extracted and prepared in the Packaging Research Laboratory of the Food Science and Industry Department, Faculty of Agriculture, Ferdowsi University of Mashhad.

2.2. Preparation of the film

Purchased pistachio meal was produced by oil extraction of Kerman Ohadi pistachio variety and under mechanical pressing. First, 9 grams of pistachio meal protein were weighed and then 100 cc of distilled water and glycerol at three concentration levels (0.3, 0.5 and 0.7) g/g of pistachio meal protein were added to the solution and its pH was adjusted with 0.1 normal sodium hydroxide at three levels (10, 11 and 12). In the next step, the resulting mixture was heated at 80 °C for 30 minutes. Then, in order to remove bubbles, the above mixture was centrifuged for 5 minutes by a centrifuge (Heraeus-200 model, made in Germany) at 5000 g. At this stage, 24 cc of the obtained clear solution was spread evenly on a completely flat aluminum plate (6 cm × 20 cm) to dry for 24 hours in the presence of air at a temperature of 25 °C. After 24 hours, the film was gently removed from the plate (Figure 1). Then, the prepared films were stored in polyethylene plastic bags in the laboratory for one week to perform the desired tests [8]. In the current study, the aim was to investigate the effect of glycerol as a plasticizer (softener) and pH on the quality of film preparation from pistachio meal. Therefore, there is no control sample. The desired levels of glycerol and pH were applied to the treatments and the properties (microscopic properties, microscopic properties, water vapor permeability and oxygen permeability) were investigated and finally the optimal treatment was selected.

Fig. 1. Image from the pistachio meal protein film

2.3. Scanning Electron Microscope (SEM) Properties Evaluation

A scanning electron microscope (model VACO-5, made in Germany) was used to study the microstructure of plasticized films.

2.4. Mechanical properties

To measure mechanical properties according to ASTM 882 (ASTM 1997), a universal testing machine (model M/10, MTS, Switzerland) was used.

2.5. Water vapor permeability (WVP)

Water vapor permeability was measured according to ASTM 96 (ASTM 1995) using a WVP Tester (model L80-5000, Switzerland) [18].

2.6. Oxygen permeability (OP)

Oxygen permeability was measured using the ASTM F 1249 (ASTM1995 e) equal pressure method using an OX-Tran (Mocon, Inc., Minneapolis) (model 8030, USA). (

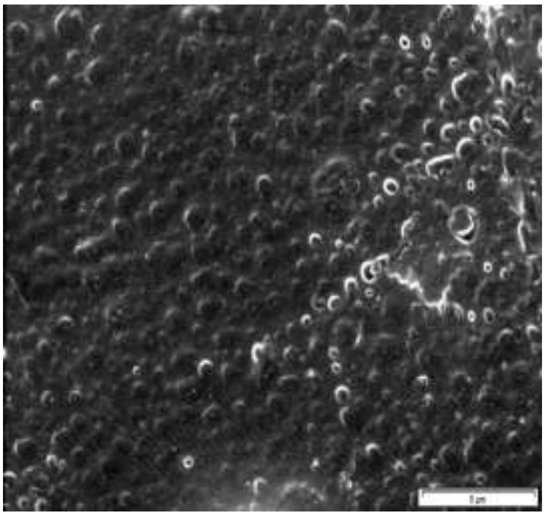
2.7. Statistical Analysis

The data were statistically tested using a completely randomized design with a factorial arrangement. Each of the film samples was produced in three replicates. Minitab software was used to analyze the variance of the results. The means of the replicates were compared using MSTATc software in the form of Duncan's multiple range test and at a statistical level of 5% ($P<0.05$).

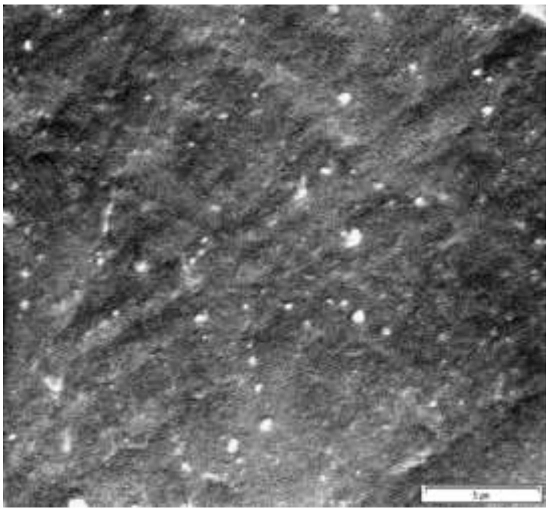
3-Results and Discussion

3.1. Scanning Electron Microscopy (SEM) Properties

SEM was used to observe and evaluate the microstructure of protein films. In the film sample with a concentration of 0.3 g/g of pistachio meal protein glycerol, a weak structure with a large number of empty spaces was observed (Figure 2(a)). Its micrograph showed that a uniform and continuous matrix is not formed in the film because there is a small amount of plasticizer to increase the cohesion between the polymer chains. This type of microstructure itself can be another reason for the high permeability of this film sample to water vapor [19]. In the film sample with a concentration of 0.5 g/g of pistachio meal protein glycerol, a compact and dense structure was observed (Figure 2(b)). The micrograph of this film showed that since there is sufficient amount of plasticizer to increase the cohesion between the polymer chains, a uniform and continuous matrix is formed in the film. This type of microstructure could be another reason for having better mechanical and physical properties than other film samples [20]. In the film sample with a concentration of 0.7 g/g of pistachio meal protein glycerol (Figure 2(c)), despite the compact and dense structure, empty spaces were also seen in the film and the reason for this is due to the high amount of plasticizer which is present to increase the cohesion between the polymer chains and causes more stretching of the film, resulting in a decrease in the mechanical properties of the film. In the study of Saremnejad et al. [21], flexible films were prepared from fava bean protein isolate at different pH levels (7, 9, and 12) and different glycerol levels (40, 50, and 60%). The optimal results (mechanical properties and water vapor permeability) at a concentration of 40% glycerol and pH of 12 were selected for the study of the film microstructure. A crack-free surface was observed with small pockets of glycerol in the protein network that could be responsible for moisture transport in the film. The cross-sectional micrograph of the film also showed a rough microstructure that was characteristic of a protein film. In another study, a difference in surface microstructure was observed between the plasticizers sorbitol and sucrose. The results showed that when 4% sorbitol and 4% glycerol were used in protein films obtained from tilapia, the films had a smooth and dense surface without cracks [22]. In the study by Sadeghi et al. [23], in order to investigate the microscopic properties, sesame meal protein film containing three levels of glycerol (40, 45, and 50 percent) was prepared. The 40 percent glycerol concentration had a smooth surface with a few cracks, indicating the uniformity of the protein film structure.



(a)



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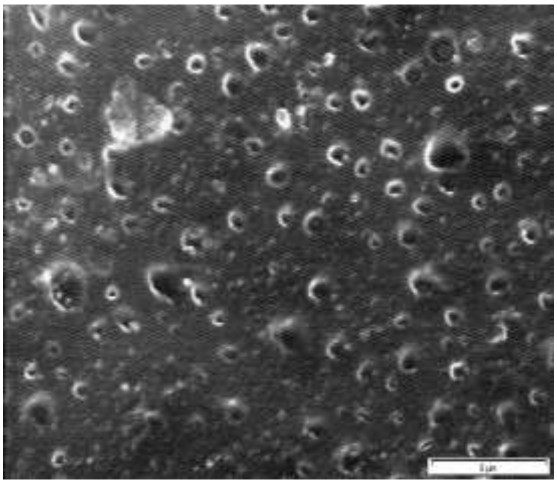


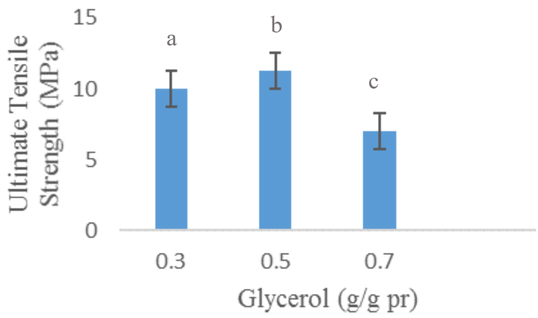
(c)

Fig. 2. Electron microscope images of (a) pistachio meal protein film with 0.3% glycerol, (b) film with 0.5% glycerol, and (c) film with 0.7% glycerol

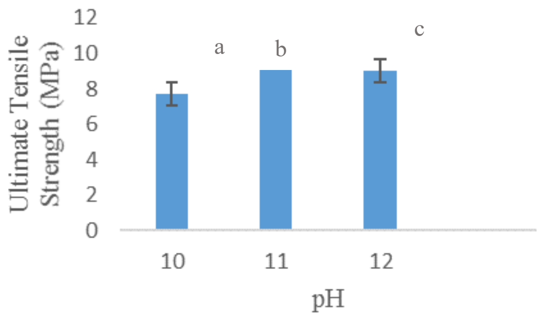
3.2. Mechanical properties

The mechanical properties of films indicate their durability and ability to enhance food preservation. The mechanical properties of protein films are affected by various factors, including the type of protein, the concentration of protein in the solvent, and the type and concentration of plasticizer. Usually, a film is mechanically desirable if it has high mechanical strength, high elasticity and flexibility, and is not brittle, but in cases where the edible film is used as a secondary packaging for food, relatively moderate to poor properties will also be acceptable [25, 24].

Figure 3(a, b, c) shows the effect of glycerol concentration, pH, and the interaction between glycerol concentration and pH on the tensile strength of the film. Statistical analyses showed that increasing glycerol concentration and pH had a significant effect on the tensile strength of the film ($P<0.05$). With increasing glycerol concentration, the tensile strength of the film increased significantly (Figure 3(a)), but when the glycerol concentration increased from 0.5 to 0.7 g/g of pistachio meal protein, the tensile strength of the film also decreased, which can be explained as follows: increasing glycerol concentration causes chains to slide over each other and reduces molecular cohesion, resulting in a decrease in tensile strength. With increasing pH, the tensile strength increased significantly (Figure 3(b)), but when the pH of the sample with a glycerol concentration of 0.5 g/g of pistachio meal protein increased from 11 to 12, a significant decrease was observed, which can be attributed to the high ionized amino acids in pistachio protein and its sensitivity to pH conditions. Since proper film formation does not occur over a wide pH range, excessive pH increases the deionization of protein side chains, reduces structural integrity, and reduces film tensile strength [27, 26]. Figure 3(c) shows the interaction effect of glycerol concentration and pH on film tensile strength. The results showed that the tensile strength of the samples was in the range of 5 and 13 MPa. Statistical analyses also showed that increasing glycerol concentration and pH had a significant effect on elongation ($P<0.05$). With increasing glycerol concentration, tensile strength increased significantly (Figure 4(d)), but when glycerol concentration increased from 0.5 to 0.7 g/g pistachio meal protein, elongation increased significantly, which can be explained as increasing glycerol concentration caused excessive weakening of the structure and as a result, the film showed greater elasticity [28]. With increasing pH, elongation increased significantly (Figure 4(e)), but when pH increased from 11 to 12, a significant decrease was observed. The reason for this can be stated as follows: excessive increase in pH causes increased deionization of protein side chains, resulting in decreased structural integrity and ultimately decreased elongation. Also, the interaction between glycerol concentration and pH (Figure 3(f)) showed that the elongation of the samples was in the range of 19.13 and 44.50% [30, 29]. Statistical analyses showed that although increasing glycerol concentration and pH had a significant effect on the elastic modulus (Figure 5(g,h)) ($P<0.05$), the interaction between glycerol concentration and pH had no significant effect on it (Figure 5(i)). With increasing glycerol concentration, Young's modulus (elastic) decreased significantly (Figure 5(g)). The reason for this can be stated as follows: with increasing glycerol concentration, the films acquire high elasticity [29, 30, 31]. With increasing pH, the modulus Young's modulus increased significantly ($P<0.05$). However, when the pH increased from 11 to 12 (Figure 5(h)), no significant difference was observed ($P>0.05$). The results of this study showed that the Young's modulus of the samples was in the range of 810.9 and 1000.4 MPa as a function of the interaction between glycerol concentration and pH (Figure 5(i)). Considering that increasing the glycerin content increases the final moisture content of the films, glycerol as a plasticizer reduces protein-protein interactions and increases the mobility of polypeptide chains, giving the films less resistance and more elasticity [32]. In a study, the highest tensile strength (4 MPa) was obtained at pH 12 and 40% glycerol content in fava bean protein films. Also, the highest elongation at break (8.37%) was obtained at pH 12 and 60% glycerol content was observed. Increasing the glycerol concentration (60%) decreased the tensile strength while leading to an increase in elongation at break. Glycerol, as a plasticizer, increased the film flexibility by reducing hydrogen bonding between protein chains and increasing the distance between the flexible fibers. Also, the thermal processing of proteins led to an increase in the cross-linking of protein chains, resulting in a tighter and more compact protein network, and ultimately increased mechanical strength [21]. Genadios et al. reported that the tensile strength of soy protein isolate was not affected by pH (6 to 9). They stated that with increasing pH, the elongation of soy protein isolate film increased slightly [33]. The effect of glycerol concentration (0.4, 0.6 and 0.8 g/g) on soy protein isolate films was investigated [34]. With increasing glycerol content, the tensile strength of the film decreased, and the lowest tensile strength was observed in films containing 0.8 g/g glycerol. Glycerol was the plasticizer resulted in greater flexibility of the film, reduced tensile strength, and consequently improved mechanical properties. In general, the film without plasticizer becomes glassy and brittle, and plasticizers bring the film closer from a glassy state to a flexible state.



(a)



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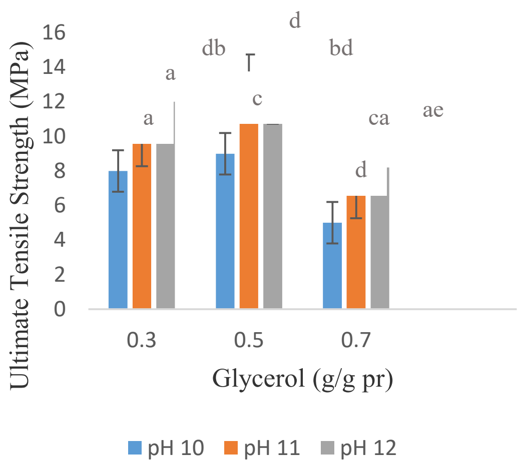
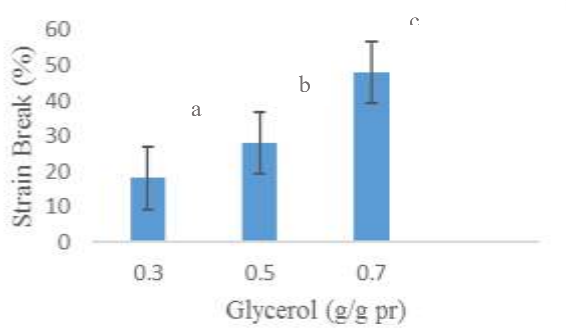
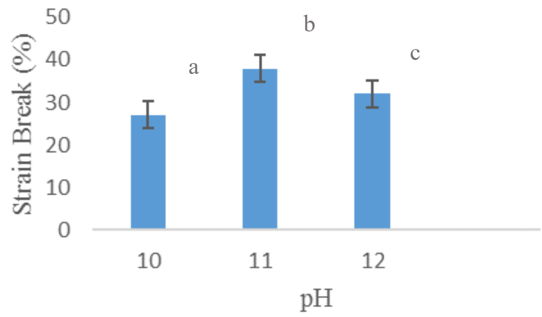


(c)

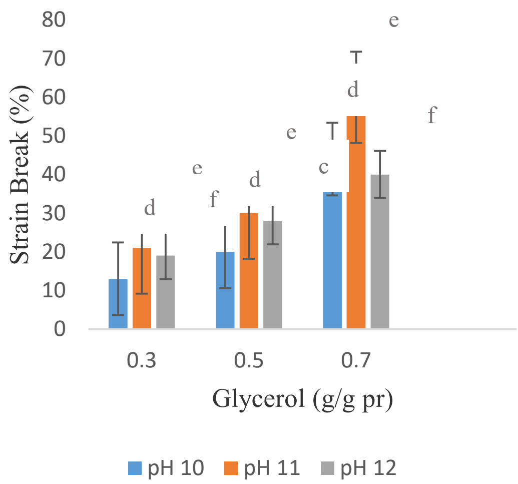
Fig. 3. Shows the effect of glycerol concentration (a), pH (b) and the interaction effect of glycerol concentration, pH (c) on the tensile strength properties of pistachio meal protein film



(**d**)

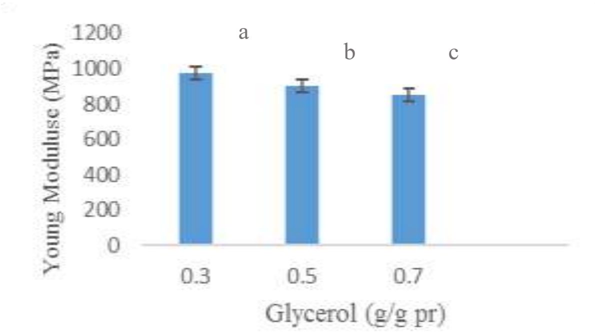


(**e**)

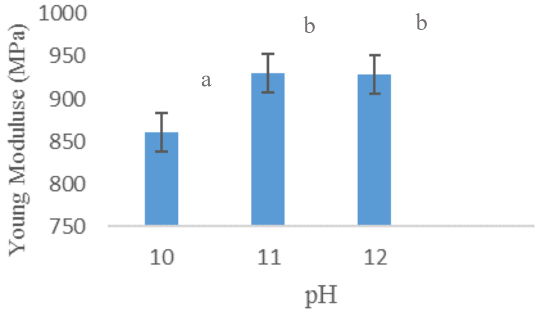


(**f**)

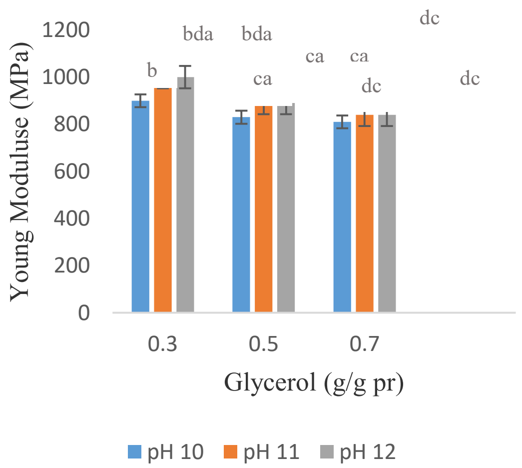
Fig. 4. Shows (d) the effect of glycerol concentration, (e) pH, and (f) the interaction between glycerol concentration and pH on the percentage elongation of pistachio meal protein film



(g)



(h)



(i)

Fig. 5. Shows (g) the effect of glycerol concentration, (h) pH, and (i) the interaction between glycerol concentration and pH on the Young's modulus of pistachio meal protein film

3.3. Water vapor permeability

The ability of a film to block water vapor is to reduce the moisture exchange of the packaged product with the external atmosphere. The mobility of the polymer chain and the interaction between the functional groups of the polymers affect water vapor permeability. Protein edible films have low water vapor resistance due to the high hydrophilic groups in the polymer chains. In the protein structure, the higher the nonpolar amino acids are compared to the polar amino acids, the higher the water vapor resistance will be [25]. All samples had relatively high water vapor permeability. As shown in Table 1, with increasing glycerol concentration from 0.3 to 0.5 g/g of pistachio meal protein, water vapor permeability decreased significantly in all samples. The reason for this can be stated as follows: by increasing glycerol concentration, proper connectivity between protein chains is created and by eliminating empty spaces and small pores in the film, water vapor molecules are not allowed to escape. However, when glycerol concentration increased from 0.5 to 0.7 g/g of pistachio protein, water vapor permeability increased significantly. This feature is probably related to the increase in chain mobility and the increase in empty spaces between polymer chains [35]. With increasing pH, the permeability to water vapor increased significantly ($P<0.05$). However, when the pH increased from 11 to 12, there was no significant difference ($P>0.05$) and the permeability to water vapor changed slightly and decreased. The reason for this can be stated as follows: in this range, pH has a greater effect on the molecular and bonding structure but does not lead to an increase in empty spaces, and even at pH 12, the permeability decreased somewhat [36]. The results of this study showed that the permeability to water vapor of the samples was in the range of 87.52 and 153.56. Orliak et al. investigated the effects of different plasticizers on the permeability properties to water vapor in films containing sunflower proteins. In all cases, the water vapor permeability of the films increased with increasing plasticizer content (glycerol, ethylene glycol, diethylene glycol, triethylene glycol, and propylene glycol). This was due to the increase in free volume between the chains, which caused the protein network to become looser. Since all the plasticizers used were hydrophilic, increasing their concentration led to greater water absorption by the network and, consequently, a higher level of vapor transmission. Propylene glycol resulted in lower values of water vapor permeability, which may be due to the higher density of the protein network. This seems to be related to the thickness of these films, which were thinner than those obtained with other plasticizers [37]. In a study, a decrease in the water vapor permeability of fava bean protein films was observed at a glycerol content of 40% and a pH of 12. The reduction in water vapor permeability as a result of heat treatment was due to the creation of more crosslinks and the formation of a more compact protein network and structure [21]. In pistachio globulin protein films, the addition of stearic acid (2, 4, and 6 wt%) (as a plasticizer) reduced water vapor permeability by 38.5 to 42%. This may be due to the increase in the proportion of hydrophobic compounds in the film [25]. In bast protein films (containing 1% glycerol), the water vapor permeability reached 25.99 mmg/m2dkpa [24]. In the study of Dehghan Shoar et al., the role of glycerol (0.4, 0.6, and 0.8 g/g) on soy protein isolate film was investigated. The results showed that with increasing glycerol content, water vapor permeability increased significantly ($P<0.05$). The glycerol plasticizer affected the hydrophilicity of the film, which was due to the high tendency of glycerol to absorb moisture. By adding glycerol, the hydrophilic hydroxyl groups on the active surface of the film increased, which resulted in an increase in the active sites for moisture absorption. It can be concluded that the hydrophilicity and concentration of glycerol have the most important effect on the tendency of the film to absorb water vapor [34].

Table 1 shows the effect of pH and glycerol concentration on the water vapor permeability of pistachio meal protein films

Film type	Plasticizer amount (g/gper)	Water wapour permeabi lity (g.mm/kpa.h.m^2)
Sample (pH=10)	0.3	145.896±0.0036 [a]
Sample (pH=10)	0.5	131.95±0.0052 [b]
Sample (pH=10)	0.7	172.65±0.0030 [c]
Sample (pH=11)	0.3	101.98±0.0051 [d]
Sample (pH=11)	0.5	87.86±0.0032 [d]
Sample (pH=11)	0.7	152.78 ±0.0028 [e]
Sample (pH=12)	0.3	100.43±0.0060 [f]
Sample (pH=12)	0.5	87.52±0.0051 [g]
Sample (pH=12)	0.7	153.52±0.0035 [g]

Lowercase letters in the column indicate significant differences at the 5% statistical level ($P<0.05$)

3.4. Oxygen permeability

A major part of the amino acids in proteins are polar amino acids (ionized and non-ionized), which is why proteins have good resistance to oxygen and carbon dioxide [38]. All samples had relatively low oxygen permeability (Table 2). By increasing the glycerol concentration to 0.5 g/g of pistachio meal protein, the oxygen permeability in all film samples decreased significantly. The reason for this can be explained as follows: with increasing glycerol concentration, the cohesion between protein chains increases and oxygen molecules are not allowed to escape. However, when the glycerol concentration increased from 0.5 to 0.7 g/g of pistachio meal protein, the oxygen permeability also increased significantly. This increase can be attributed to the increase in chain mobility and the creation of empty spaces in the protein matrix as a result of the increase in glycerol concentration [29]. With increasing pH, the oxygen permeability decreased significantly ($P<0.05$). This is because with increasing pH, The polar-ionic interactions between the side chains increased. Except when the pH increased from 11 to 12, no significant decrease was observed. The results of this study showed that the oxygen permeability of the samples was in the range of 1.58 and 5.66. Peanut protein films were investigated using four types of plasticizers (glycerin, sorbitol, polyethylene glycol and propylene glycol) at three levels (0.67, 1.17, 1.67 g/g protein) in a study. Glycerin showed the best performance as a plasticizer compared to the others. Glycerin concentration between 0.67 and 1.67 g/g protein did not affect the oxygen permeability [39]. In the study of Zahedi et al., the effect of palmitic acid (2, 4 and 6 wt%) (as plasticizer) on pistachio globulin protein films was investigated. Results showed that the addition of palmitic acid reduced the permeability to oxygen (from a concentration of 2 to 4% palmitic acid). By adding fatty acid and performing homogenization, this acid filled the open spaces in the polymer network of the film, and as a result, the rate of oxygen diffusion decreased [38]. The permeability to oxygen of films prepared from pistachio meal globulin protein was reduced as a result of the addition of stearic acid (as a plasticizer). The high polarity of the proteins increased the binding energy and reduced the free volume, resulting in a reduced gas diffusion rate. The higher the number of polar groups and the ratio of polar-ionic interactions, the greater the inhibition of the film against oxygen because oxygen is a nonpolar molecule [25]. Plasticizers cause disruption of the molecular chain and a decrease in the glass transition temperature. For the plasticization process, it is necessary that the mobility of the chains increases due to the replacement of protein interactions with protein-plasticizer interactions. The plasticizer increases the free volume of the protein and, consequently, the permeability and mobility of protein chains reduces the glass transition temperature [40].

Table 2 Demonstration of the effect of pH and glycerol concentration on the oxygen permeability of pistachio meal protein films

Film type	Plasticizer amount (g/gper)	Oxygen permeability ($cm^3.\mu/cm^2.d.Kpa$)
Sample (pH=10)	0.3	3.93±0.728 [a]
Sample (pH=10)	0.5	2.86±0.001 [b]
Sample (pH=10)	0.7	5.66±0.908 [c]
Sample (pH=11)	0.3	2.83±0.761 [d]
Sample (pH=11)	0.5	1.81±0.959 [e]
Sample (pH=11)	0.7	4.37 ±0.154 [f]
Sample (pH=12)	0.3	2.19±0.231 [a]
Sample (pH=12)	0.5	1.58±0.765 [e]
Sample (pH=12)	0.7	3.38±0.975 [a]

Lowercase letters in the column indicate significant differences at the 5% statistical level ($P<0.05$)

4- Conclusion

Pistachio meal is a cheap, available and rich source of protein. Flexible films were prepared from pistachio meal protein at different pH levels (10, 11 and 12) and different concentrations of glycerol plasticizer (0.3, 0.5 and 0.7) g/g pistachio meal protein. In this study, it was shown that with increasing glycerol concentration, the tensile strength and elongation of the samples increased, while the elastic modulus decreased. Increasing pH increased the tensile strength, elongation and elastic modulus of pistachio meal protein films. The results of the barrier properties of the biodegradable film samples indicated that increasing glycerol concentration and pH significantly reduced the permeability to oxygen and water vapor. So that at pH 11 and a concentration level of 0.5 g/g of glycerol protein, the values of oxygen and water vapor permeability were 1.81 cm3.µ/cm2.d.Kpa and 87.86 g.mm/kpa.h.m2, respectively. Based on the findings of this study, the best solution for preparing biodegradable film based on pistachio meal protein was selected at a concentration level of 0.5 g/g of glycerol protein and pH 11. Therefore, such films can have high potential for high solubility film applications by applying various modification methods such as adding other protein materials. Pistachio meal protein film can have numerous applications in the food packaging industry in the near future.

Conflict of Interest

The authors have no conflicts of interest

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All activities were carried out by the authors.

5-Reference

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مقاله علمی_پژوهشی

تولید فیلم زیست تخریب پذیر بر پایه پروتئین کنجاله پسته و بررسی ویژگی های فیزیکوشیمیایی آن

فریما آقایی[۱]، ناصر صداقت[۲*] ، نرجس جنتی ها[۳]، علی شریف[٤]

۱-کارشناسی ارشد، گروه علوم و صنایع غذایی، دانشکده کشاورزی دانشگاه فردوسی مشهد، مشهد، ایران

۲*-استاد ، گروه علوم و صنایع غذایی، دانشکده کشاورزی دانشگاه فردوسی مشهد، مشهد، ایران

۳-دانشجوی دکتری، گروه علوم و صنایع غذایی، دانشکده کشاورزی دانشگاه فردوسی مشهد، مشهد، ایران

٤-استادیار ، گروه علوم و صنایع غذایی، دانشکده کشاورزی دانشگاه فردوسی مشهد، مشهد، ایران

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* مسئول مکاتبات:

sedaghat@um.ac.ir

چکیده

کنجاله پسته عمده ترین بخش محصولات جانبی کارخانجات روغن کشی پسته (بیش از ٦۰ درصد) را تشکیل می دهد. در کنجاله پسته ترکیبات با ارزش تغذیه ای شامل پروتئین، مواد معدنی و ویتامین ها وجود دارد. همچنین، کنجاله پسته منبعی غنی از پروتئین است. هدف از انجام این پژوهش، تولید فیلم زیست تخریب پذیر از پروتئین کنجاله پسته و بررسی تأثیر تیمارهای غلظت گلیسرول در سه سطح (۰/۳، ۰/۵و ۰/۷) گرم بر گرم پروتئین کنجاله پسته و pH در سه سطح (۱۰،۱۱و ۱۲) بر ویژگی های فیلم (خواص مکانیکی، نفوذ پذیری به اکسیژن و نفوذ پذیری به بخار آب و خواص میکروسکوپی) بود . نتایج خواص مکانیکی نشان داد با افزایش غلظت گلیسرول، مقاومت به کشش و ازدیاد طول افزایش پیدا کرد، در حالی که مدول الاستیک کاهش یافت ($P<۰/۰۵$). افزایش pH باعث افزایش مقاومت به کشش، ازدیاد طول و مدول الاستیک شد ($P<۰/۰۵$). بررسی خواص بازدارندگی نمونه های فیلم زیست تخریب پذیر نشان داد که افزایش غلظت گلیسرول و pH اثر معنی داری بر نفوذ پذیری نسبت به اکسیژن و بخار آب داشت ($P<۰/۰۵$). با افزایش غلظت گلیسرول و pH نفوذ پذیری نسبت به اکسیژن و بخار آب کاهش یافت ($P<۰/۰۵$) و در بررسی مورفولوژی ساختار فیلم های زیست تخریب پذیر مختلف، خصوصیات فیزیکوشیمیایی نمونه ها کاملا" با میکروگراف های بدست آمده تطبیق داده شد. بنابراین فیلم بهینه بر پایه پروتئین کنجاله پسته درسطح غلظت ۰/۵ گلیسرول (گرم بر گرم پروتئین کنجاله پسته) و pH برابر ۱۱ انتخاب شد.