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PACKAGING OF REFRIGERATED STRAWBERRY (*Fragaria ananassa*) USING PREPARED EDIBLE WHEAT GLUTEN FILMS AND COATINGS

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ABSTRACT

Edible films and coatings from wheat gluten were prepared with different concentrations of glycerol (as plasticizer), and at pH (10). The effect of different wheat gluten films, and coatings on refrigerated strawberry quality, and shelf life was studied. Films with low amounts of glycerol (20%) had lower water vapor and other properties *e.g.* tensile strength was recorded the highest value, on the contrary, the water solubility as well as the elongation properties were in lower values at break. The best prepared film properties were for (25%) glycerol content. The quality of strawberry fruits packed in wheat gluten film was superior to corresponding fruits packed in perforated polypropylene films for all tested parameters *i.e.* visible decay, surface color development, weight loss, firmness loss, and sensory characteristics . Different layers were used to prepare different coatings based on wheat gluten: (I) one layer of wheat gluten only. (II) One layer of wheat gluten with beeswax and lipids (stearic, and palmitic acids). (III) bilayer coating of wheat gluten. The bilayer coating had a significant effect on the retention of strawberry firmness, and showed reduction on their weight loss compared with the uncoated fruits. Results showed also that, the gluten coatings were more able to control the decay than those of gluten film (pouch film). Sensory tests after different storage periods at (5^0C) up to 16 days compared with control was done. The coated strawberry maintained their visual quality during storage periods. As a result the taste of gluten coated strawberry was more acceptable at the end of storage compared with the control.

Key words: *edible coating , glycerol , mechanical properties, quality , shelf life , strawberries , water vapor, wheat gluten films.*

1. INTRODUCTION

Coating and edible films have long been known to protect perishable food products from deterioration and some types of quality loss. However, over the last decade there has been a rapidly growing interest in the development and use of biobased packaging materials to prolong the shelf-life and improve the quality of fresh, frozen and formulated food products because of the following factors: (a) environmental issues related to disposal of conventional synthetic food-packaging materials and the need to develop more ecofriendly and biodegradable materials; (b) increasing consumer expectations for a variety of fresh-like foods (*e.g.* minimally processed fruit and vegetables); (c) the need for food products with extended shelf-life; (d) expanding distribution channels for food commodities; and (e) new opportunities for food products with edible barriers, (Krochta and DeMulder-Johnston 1997). Although many functions of edible films and coatings are identical to those of synthetic films, there are additional requirements pertaining to their use in foods, (Debeaufort, *et al*., 1998) (a) acceptable sensorial characteristics; (b) appropriate barrier properties (gas, water, oil); (c) good mechanical strength and adhesion; (d) reasonable microbial, biochemical and physicochemical stability; (e) safety for health (free of toxic micro-organisms and hazardous compounds); (f) effective carrier for antioxidant, flavor, color, nutritional or antimicrobial additives; (g) raw materials of low cost; and (h) simple technology for production. Many of the current research efforts on biopackaging of foods aim at one or more of these issues, all relevant to the performance of edible films and coatings. (Diab *et al*., 2001).

Production and utilization of edible, biodegradable films and coatings prepared from various biological polymers such as polysaccharides, proteins, lipids or combinations of those components have received great interest in recent years. Among other materials, proteins have long been used for this biopolymer production, (Kayserilioglu, *et al*., 2003). Wheat gluten is a biodegradable and crop renewable agropolymer with interesting film-forming properties for the production of biopackaging materials, and its unique among cereal and other plant proteins in its ability to form a cohesive blend with viscoelastic properties once plasticized. In general, gluten-based materials require addition of plasticizer agents, (Mastromatteo, *et al*., 2008). Glycerol is one of the most popular plasticizer used in filmmaking techniques due its stability and compatibility with hydrophilic biopolymeric chain (Pommet, *et al.*, 2005). These small molecules interact with the polymer chains, thereby lowering forces holding the chains together. Similar to other protein films, wheat gluten films are excellent oxygen and carbon dioxide barriers at low relative humidities with selective permeability to gases (Mujica-Paz and Gontard, 1998).

Recently, there has been an increasing consumers demand for fresh and minimally processed fruits and vegetables due to their fresh-like character, convenience, and human health benefits. Fresh fruits and vegetables are characterized by a post-harvest respiration activity, which could be correlated to the deterioration rate of the product during storage (Ahvenainen, *et al.*, 1998). Low storage temperature and/or modified atmosphere packaging (MAP) are commercially used for reducing the respiration rate, delaying senescence and ultimately increasing product shelf-life of packaged fruits and vegetables, (Mujica Paz, and Gontard 1998).

Strawberries are a soft fruit with high respiration and softening rates, making the availability of high quality strawberries challenging. Due to its high metabolism, strawberries must be kept at 4–5° C, which can extend its high quality for 6 or 7 days. The use of coating or edible film involving strawberries can also be an alternative to improve their shelf- life (Tanada-Palmu, and Grosso, 2005).

The objectives of this study were to investigate the effect of prepared edible wheat gluten films with different amounts of glycerol on the film properties (water solubility, water vapor permeability and mechanical properties). The study also points to the ability of gluten-based coatings and films to extend the shelf-life of refrigerated strawberries. The influences of different types of coatings and films on the quality attributes of strawberries, such as weight loss, firmness retention, surface color development and sensory evaluation were also studied.

2. MATERIALS AND METHODS

Wheat gluten was obtained from Tate and Layle, Companies, France, the other ingredients used to prepare gluten films were distilled water, sodium sulfate, ethanol (96%), ammonium hydroxide, glycerol (98%), fatty acids, (stearic and palmitic acids). Beeswax was used as an additional additive for coatings.

Silicagel was used for determination of water vapor. Perforated polypropylene film, Organic strawberries fresh fruit (*Fragaria ananassa*) was obtained from the Faculty of Agriculture Farm – Cairo University.

2.1. Preparation of wheat gluten film

Films based on wheat gluten (100 ml) were prepared according to Gontard *et al.*, (1992) with some modification by Irissin-Mangata *et al.*, (2001). Sodium sulfate (0.3g/100g dry gluten matter), was dissolved in 50 ml of distilled water then added to 7.5 g of wheat gluten in order to cut the disulfide bonds of the gluten proteins. The components were mixed until complete homogeneous (no insoluble particles present). Ethanol (45 ml) was added to the previous solution. Glycerol was also added at concentrations of 20, 25, 30, 35, 40, 45, 50, 55, 60, or 70% (w/w) of gluten, then 6N ammonium hydroxide (NH_4OH) was used to adjust the of solutions to pH 10. All components were mixed on a hot plate equipped with a magnetic stirrer until the temperature of the mix reached to 70^0C (about 10 min) to improve the dispersion of gluten protein. The film-forming solution was poured and spread evenly over a Teflon Plate and dried at room temperature for 24 h as recommended by Tanada-Plamu *et al.* (2000).

2.2. Film thicknesses

Film thickness was measured using a micrometer (Model 49 - 50 - 02, Messmer Instrument, Germany). The thickness of the individual film samples was determined as an average of five measurements as recommended by Tanada-Palmu, and Grosso (2002).

2.3 Opacity

Film opacity determined as described by Gontard *et al.*(1992). The film sample was cut into a rectangle (7-25 mm) shaped strips and placed on the internal side of a spectrophotometer cell. The absorbance of spectrum (400-800 nm) was recorded for each sample using an Ultraspec 2100 *pro* UV / visible spectrophotometer, USA. Film opacity was defined as the area under the recorded curve determined by an integration procedure. The opacity was expressed as Absorbance Units in nanometers (AU. nm).

2.4. Weight loss in water

The weight loss of film in water was determined according to the method of Irissin-Mangata *et al.*(2001). The film dispersion in water was defined by the content of dry matter that was lost after 24 h of immersion. Two discs of each film (2 cm diameter) were cut and weighed. One was dried at 104^0C / 24 h to determine the percentage of initial dry matter. The other disc was immersed in 50 ml of distilled water containing of sodium azide (0.02 % w/v) to prevent growth of microorganisms. After 24 h immersion at 25^0C with occasional stirring, the pieces of film were removed and dried to constant weight at 104^0C for 24 h to determine the weight of dry matter that was dispersed in water. The final result of the film dispersion in water calculation was the average value of 3 measurements.

2.5. Water vapor permeability

Water vapor permeability (WVP) of the film was determined gravimetrically at 30^0C as described by Gontard, *et al*., (1992) and Irissin-Mangata, *et al*, (2001). The tested film (discs of 37 mm diameter) was sealed with silicone grease in cups containing silicagel (0% RH; 0 mmHg water vapor pressure) and the cups (3.7 X 4.5 X 3.5 cm^3) were placed in a desiccator containing distilled water to obtain RH gradient equal to 100% (32.23 mmHg water vapor pressure). The water vapor was determined from the weight gain of the silicagel recorded at various times. The cups were weighed initially and at 6, 24, 48 h intervals. Changes in weight of the cups were recorded to the nearest (0.1 mg). The permeability (P) of the film was determined as follows;

$$WVP = (w * x) / A * T * (P_2-P_1) = (g)* (mm)/ (m^2)* (24h)* (mmHg)$$

Where (W) is the weight gain of permeation cell after 24 h (T); (x) is the film thickness ; (A) is the area of exposed film; (P_2-P_1) is the vapor pressure differential across the film (32.23 mmHg).

2.6. Tensile strength and percentage elongation at break

Film tensile strength and percentage elongation at break were determined using (A Houns Fiel D machine model H5KS, Germany) as described by Tanada-Plamu, *et al.* (2000). Measurements were conducted at ambient temperature (25^0C). Initial grip separation and crosshead speed were set at 100 mm and 100 mm/min, respectively. Peak loads and extension at break point were recorded for tested film specimens (150 mm long and 20 mm wide). Tensile strength of the sample was calculated by dividing peak load by cross sectional area. Thickness of individual specimens, required to calculate cross-sectional area, was determined as an average of five micrometer reading taken on each specimen before testing. Dividing extension values by the initial grip separation (100 mm) and multiplying by 100 yielded percentage elongations at break.

2.7.Application of the edible film to fresh strawberries

2.7.1. Sample preparation

Organic strawberries (*F. ananass*a) at the commercially ripe stage (75% red color), grown in a green house in the Faculty of Agriculture Farm, Cairo University were harvested and treated in the next day. An amount of 280 fruits of uniform size, free of physical damage and fungal infection, was used. Strawberries were dipped in water and dried using tissue paper. Forty fruits, distributed randomly in four trays with 10 fruits in each tray, were used in each treatment. One tray (with 10 fruits) of each treatment was removed from the refrigerator(5°C) at 1, 6, 12 and 16 days of storage and used for the analyses. Six treatments were conducted. Preparation of strawberries was performed according to the method of Tanada-Plamu, and Grosso, (2002).

2.7.2. Wheat gluten – based coatings and films

The edible wheat gluten film was applied to coat fresh strawberries to evaluate the influence of film on weight and firmness losses of the product. Four treatments were carried out to cover fresh strawberries with the gluten film as coatings and other two treatments were used as packed in films. In treatment (I) fresh strawberries were dipped into the film-forming solution (7.5 g gluten + 1.87 g glycerol + 45 mL ethanol/100 mL solution, and pH 10) at room temperature (25°C for 1 minute (min). In treatment (II) strawberries were dipped into the same film-forming solution as treatment (I) for 1 min and allowed to dry for 1 h; then they were dipped again into the same solution for 1 min in order to form a bilayer gluten film over the strawberries as indicated by Tanada-Plamu, and Grosso (2002). In treatment (III) the composite coating formulation was prepared by the addition of 0.45 g of beeswax, 0.27 g of stearic acid and 0.27 g of palmitic acid into the gluten coating formulation. This lipid containing solution was heated to 70°C to melt time, the lipids under vigorous magnetic stirring. In treatment (IV) (control), strawberries were dipped into distilled water for 1 min. In treatment (V) the wheat gluten films were designed as (pouch film), pouches were prepared by first folding the gluten film in the middle and hot-sealing two sides of the film, then putting the strawberry inside the pouch and hot-sealing the third side of the film. In treatment (VI) strawberries were packed in perforated poly propylene. After that, all trays with strawberries were transferred into the refrigerator at 5°C and 60–80% RH for 16 days to follow the shelf -life effect.

2.7.3. Strawberry visible decay

One tray (with 10 fruits) of each treatment was inspected after 6, 12 and 16 days of storage and the fruits were considered infected when a visible lesion was observed as recommended by Tanada-Palmu, and Grosso, (2005). The visible microbial attack on the fruit was characterized as brown spots and a softening of the injured zone. The results were expressed as the percentage of infected fruits.

2.7.4. Weight loss

Three fruits from the tray of each treatment were weighed at the beginning of the experiment and after 1, 6, 12 and 16 days of storage as described by Tanada-Palmu, and Grosso, (2005). The trays of day 16 were chosen to follow the weight loss, since these trays would only be analyzed on the last day of the experiment. At every day of analysis, for the fruits in the gluten pouch or perforated polypropylene film, the film was taken out to weigh the same three fruits and then packed again with the same film and stored at refrigerator to continue the experiment. The results were expressed as percentage loss of initial weight.

2.7.5. Firmness "shearing force"

Shearing force of strawberry fruits was measured using (AMETEK /MANSFIELD & GREEN DIV. LARGO. FLORIDA 33543, Model No. ML 3339-8). Determinations were performed on three fruits from the tray of each treatment after 1, 6, 12 and 16 days of storage were the dimensions of (2x1 cm). Firmness retention was calculated as $(F_t/F_0) \times 100$, with F_t as the shear force at time t and F_0 as the shear force at the beginning of the experiment as described by Tanada-Palmu, and Grosso, (2005) .The results were expressed as percentage of firmness retention.

2.7.6. Surface color development

Colorimetric measurements of the fruit surface were carried out with a Hunter lab Colorimeter Model D25 optical sensor (Hunter Associates Laboratory, Inc Reston, Virginia, USA) as described by Tanada-Palmu, and Grosso, (2005). The chromaticity parameters a and b were registered on strawberries (three fruits from the tray of each treatment) after 1, 6, 12 and 16 days of storage. There were two determinations for each strawberry, in each side of the fruit, so the results were expressed as the mean of six determinations for each treatment.

2.7.7. Sensory evaluation of the strawberries

The qualities of different samples of strawberries either coated or packed in films as well as the control sample were evaluated. The strawberries were evaluated after 1, 6, and 12 days of cold storage by ten panelists from the staff of Food Science and Technology Department, Faculty of Agriculture, Cairo University. The attributes analyzed were color, brightness flavor, texture and over all acceptability according to Tanada-Palmu, and Grosso (2005).

2.8. Statistical analysis

Results were statistically analyzed by the least significant differences (L.S.D) at the level of probability procedure according to Snedecor and Cochran (1980).

3. RESULTS AND DISCUSSION

3.1 Characteristics of prepared films

Plasticizers are generally added to films to reduce brittleness, impart flexibility, and increase strength, tear resistance and impact resistance (Banker 1966) and (Tanada-Plamu, *et al.*, 2000). Results in Table (1) show the characteristics of (WG) films plasticized with glycerol. At 20% added glycerol the film was brittle and fragile, however using 25% added glycerol, the film was flexible and transparent, this characteristics was with the different added concentration of glycerol up to 50%; in contrast, the film become soft up to 60%; added glycerol. At 70% added glycerol the film was too soft.

The mechanism by which plasticizers achieved such changes involves plasticizer – polymer interaction and reduction of cumulative intermolecular forces along polymer chains leading to "softening" of the film structure (Gennadios *et al.*, 1993).

Table (1):Characteristics of wheat gluten (WG) films plasticized with glycerol (GLY) at ambient temperature and relative humidity.

Film	Characteristics
Wheat gluten with: 20 % GLY	brittle and fragile
25% GLY	Flexible and transparent
30% GLY	Flexible and transparent
35% GLY	Flexible and transparent
40% GLY	Flexible and transparent
45% GLY	Flexible and transparent
50% GLY	Flexible and transparent
55% GLY	Flexible, transparent and soft
60% GLY	Flexible, transparent and soft
70% GLY	Too soft

3.2. 3.2.Water vapor permeability

Water vapor permeabilities (WVP) of wheat gluten films with different levels of glycerol at 30^0C and 0/100 % relative humidity are shown in

Table (2). Significant differences among all the tested film samples are clearly shown. The lowest WVP was for the film containing 25% glycerol. As the concentration of glycerol increased the WVP increased that means directly proportional. As shown by Gontard *et al.*(1993); Park *et al.*, (1994), and Tanada-Palmu, *et al.*(2000) found that water vapor permeability (WVP) increased with increasing glycerol concentration.

By the modifications of the protein structure, which might become less dense, and by the hydrophilicity of glycerol, which favors adsorption and desorption of water molecules in addition the WVP should be as low as possible, since an edible film or coating should retard moisture transfer between the food and the environment, or between two components of a heterogeneous food product (Gontard *et al.*, 1992).

Table (2). Water vapor permeability (WVP) of wheat gluten (WG) films with different levels of glycerol at 30^0C and 0/100 % relative humidity.

Film	Tensile strength (MPa)	Break N	Elongation %
Wheat gluten with:			
25% GLY	7.88 ^{a}	10.63 ^{a}	133.13 ^{e}
30% GLY	7.42 ^{a}	10.01 ^{a}	167.47 ^{d}
35% GLY	7.09 ^{ab}	8.31 ^{b}	229.43 ^{c}
40% GLY	6.03 ^{b}	7.23 ^{b}	249.37 ^{c}
45% GLY	3.54 ^{c}	4.25 ^{c}	253.40 ^{c}
50% GLY	2.93 ^{cd}	4.18 ^{c}	289.40 ^{b}
55% GLY	2.45 ^{d}	4.74 ^{c}	293.37 ^{b}
60% GLY	2.31 ^{cd}	5.34 ^{c}	329.33 ^{a}

3.3. Mechanical properties

An edible film should be resistant in order to withstand the manipulation during its application and to maintain its integrity and also its barrier properties, (Tanada-Plamu, and Grosso, 2002). Tensile strength was decreased and the percentage elongation at break was increased with increasing glycerol concentration as shown in Table (3). Apparently, glycerol is a small hydrophilic molecule which could be inserted between protein chains. With glycerol in the protein network the distance between protein chains was increased and direct interactions were reduced. An alkaline environment and heating are necessary to denature the gluten protein, thus disrupting protein structure, breaking existing disulfide intramolecular bonds and exposing sulphydryl and hydrophobic groups, making them available for bonding. The cleavage of disulfide bonds results in polypeptide chains with lower molecular weights, destroying elasticity and cohesiveness of gluten. Upon casting and drying, sulphydryl groups reform disulfide bonds by air oxidation, which leads the film structure (Gennadios *et al.*, 1993).

Table (3): Mechanical properties of wheat gluten (WG) films with different levels of glycerol.

Film	Water vapor permeability (gmm/m^{2}dkpa)
Wheat gluten with:	
25% GLY	2.5 ^{f}
30% GLY	2.7 ^{ef}
35% GLY	2.8 ^{def}
40% GLY	3.2 ^{de}
45% GLY	3.4 ^{d}
50% GLY	4.5 ^{c}
55% GLY	6.1 ^{b}
60% GLY	7.2 ^{a}

Table (4): Solubility in water and opacity of wheat gluten (WG) films with different levels of glycerol.

Film	Solubility in water %
Wheat gluten with:	
25% GLY	12 ^{c}
30% GLY	14.8 ^{c}
35% GLY	16.7 ^{bc}
40% GLY	38.5 ^{ab}
45% GLY	42.6^{a}
50% GLY	33.2 ^{ab}
55% GLY	39.1 ^{a}
60% GLY	40.9 ^{a}
The LSD at 5%	**22.15**

3.4.Solubility in water

Solubility (%) of wheat gluten film with different levels of glycerol in water is shown in Table (4). Results show that, as the percentage of glycerol (plasticizer) increased with the solubility of the prepared film increases. These results are in accordance with those obtained by Tanada-Plamu, and Grosso.(2002) who found that the solubility (%) of WGF with 25% glycerol was 11.1%, meanwhile it was found to be 17.4% solubility for the WGF prepared with 35% glycerol. The solubility matter in water is likely consisted of the plasticizer and some protein chains of low molecular weight (Cuq *et al.*, 1997).

Water resistance is an important property of edible films for applications in food protection, where water activity is high, or when the film must be in contact with water during processing of the coated food to avoid exudation of fresh or frozen products (Gontard *et al.*, 1993).

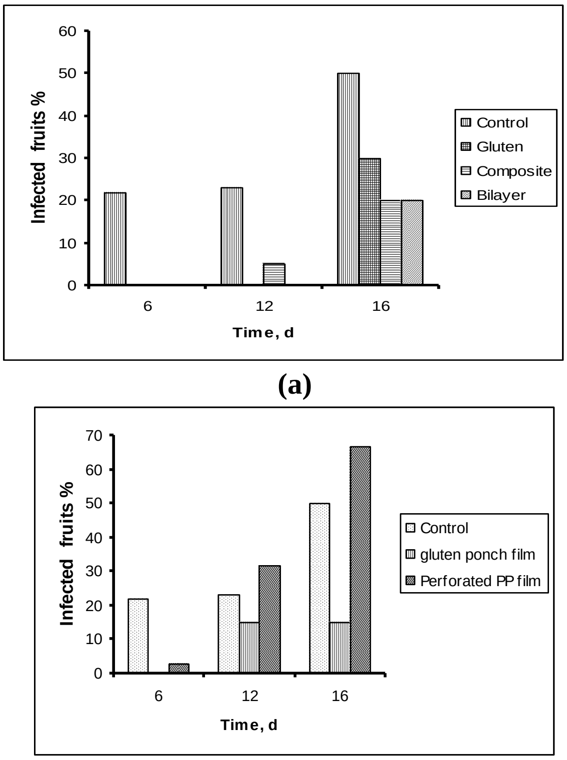
3.5. Wheat gluten coatings and film as well as synthetic film (perforated polypropylene) for strawberries packaging

Edible wheat gluten coatings (one layer, bilayer and composite) and other films were applied for strawberry fruits in order to rmoisture and firmness losses and also to extend the shelf

Table (5): Mean of the attributes in the sensory evaluation for the shelf life of four samples of strawberry stored at 5°C during 16 days.

Parameter	**Treatment**	**Storage time at 7-10^{0}C**			
		1 day	**6 days**	**12 days**	**LSD at 5%**
Color	Control	7.8^{bA}	6^{cA}	3.5^{cB}	2.14
	Coatings:				
	▪ Gluten (one layer)	7.3^{bA}	8.1^{abA}	5.4^{abB}	1.68
	▪ Composite	8.1^{abA}	8.4^{abA}	6.9^{aA}	0
	▪Bilayer	8.7^{aA}	8.8^{aA}	6.9^{aA}	0
	Films:				
	▪ Gluten pouch film	7.9^{bA}	6.8^{bcA}	4.9^{bcA}	0
	▪ Perforated polypropylene	6.4^{cA}	6.1^{cA}	3.9^{bcB}	1.25
	LSD at 5%	0.88	1.85	1.55	
Brightness	Control	5.3^{bA}	4.9^{bA}	2.9^{cB}	2.14
	Coatings:				
	▪ Gluten (one layer)	7.8^{aA}	7.5^{aA}	4.9^{abB}	1.76
	▪ Composite	8.3^{aA}	8.1^{aA}	6.5^{aA}	0
	▪Bilayer	8.4^{aA}	8.8^{aA}	6.6^{aA}	0
	Films:				
	▪ Gluten pouch film	6.1^{bA}	5.9^{bcA}	4.1^{bcA}	0
	▪ Perforated polypropylene	5.4^{bA}	4.6^{cA}	2.9^{bcB}	1.36
	LSD at 5%	1.15	2.03	1.83	
Flavor	Control	9.2^{aA}	9.4^{aA}	7.1^{aB}	0.83
	Coatings:				
	▪ Gluten (one layer)	6.7^{cA}	5.4^{cA}	4.7^{cB}	1.17
	▪ Composite	7^{bcA}	6.1^{bcA}	5^{bcA}	0
	▪Bilayer	8.3^{abA}	8.2^{abA}	6.2^{abA}	0
	Films:				
	▪ Gluten pouch film	8.5^{aA}	7.4^{bA}	5.8^{bB}	1.67
	▪ Perforated polypropylene	8.1^{abA}	7.1^{bcA}	5.2^{bcB}	1.35
	LSD at 5%	**1.32**	**1.39**	**1.27**	
Texture	Control	9.1^{aA}	6.9^{cbB}	3.2^{cC}	2.28
	Coatings:				
	▪ Gluten (one layer)	7^{bA}	7.6^{abcAB}	4.4^{bcB}	1.76
	▪ Composite	7^{bA}	8.4^{abcA}	6.4^{abA}	0
	▪Bilayer	7^{bA}	8.7^{aA}	7.1^{aA}	0
	Films:				
	▪ Gluten pouch film	8.3^{abA}	7^{cbA}	4.1^{cB}	1.63
	▪ Perforated polypropylene	7.6^{bA}	6.3^{cA}	3.4^{cB}	1.52
	LSD at 5%	**1.01**	**1.67**	**2.02**	
Overall acceptability	Control	6.3^{bA}	5.2^{cA}	4.1^{eC}	1.66
	Coatings:				
	▪ Gluten (one layer)	7^{abA}	7.4^{abAB}	5.9^{bcB}	1.37
	▪ Composite	7.1^{abA}	8.2^{abA}	7.5^{aA}	0
	▪Bilayer	8^{aA}	8.6^{aA}	6.8^{abA}	0
	Films:				
	▪ Gluten pouch film	6.9^{abA}	6.7^{bcA}	5.4^{cdA}	0
	▪ Perforated polypropylene	6.1^{bA}	5.8 cA	4.5^{deA}	0
	LSD at 5%	**1.13**	**1.59**	**1.83**	

-life of the fruits that are indicated by visible decay during cold storage (16 days) as recommended by Tanada-Palmu and Grosso (2005) and Garcia *et al*. (1998a).



(a)

(b)

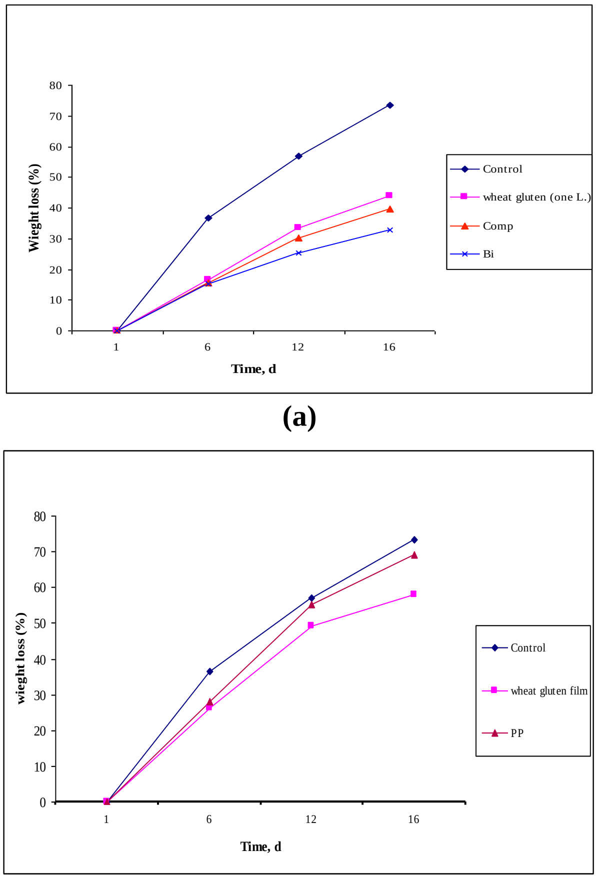
Fig. (1). Visible decay of strawberries either coated (a) or packed in films (b). Results expressed as percentage of infected fruit during storage time.

3.5.1. Strawberry visible decay

Strawberry is a highly perishable fruit and the shelf life usually ends due to fungal infection (Maas, 1981). In this work, the maximum storage life was defined as the time elapsed between the application of coatings as well as films and the visualization of fungal injury. Percentage (%) of infected fruits was 22% for the control fruit during the storage time after 6 days. Shelf-life of the Gluten and bilayer coated fruit and the fruit maintained in the gluten pouch film extended up to 12 days without decay. These results are reported by Tanada-Palmu, and Grosso (2005) and Garcia *et al*. (1998a), who found that the coatings and pouch film markedly reduced the number of infected fruits and extended the storage life. However, perforated polypropylene did not reduce the number of infected fruit at the end of the storage time as compared to the control treatment (Fig. 1b). The gluten pouch film and the coatings of one layer gluten, bilayer and composite were significantly reduced the number of infected fruit in comparison with the control fruits at the end of the experiment (Fig. 1a). The gluten film was more effective for reducing the number of infected strawberries than the coated fruits. The films and coatings can reduce decay by delaying senescence, which makes the commodity more vulnerable to pathogenic infection as a result of the loss of the cellular or tissue integrity (Tanada-Palmu, and Grosso, 2005).

3.5.2. Weight loss

Weight loss of the fruits increased with the storage time for the control and those coated or packed with films (Fig. 2 a &b). Results showed a significance increases in weight loss for all treatments. However, the weight loss of the control sample was significantly higher than the other treatments. On the contrary, the strawberry fruits coated with the bilayer coating were superior than the other treated samples that had the lowest weight loss (Fig. 2a). A similar effect was also observed by Garcia *et al*. (1998a, 1998b) for strawberries coated with starch-based coatings and those by Tanada-Plamu, and Grosso (2002). The same bilayer coating significantly reduced the weight loss of strawberries comparing to a single layer of gluten coating.



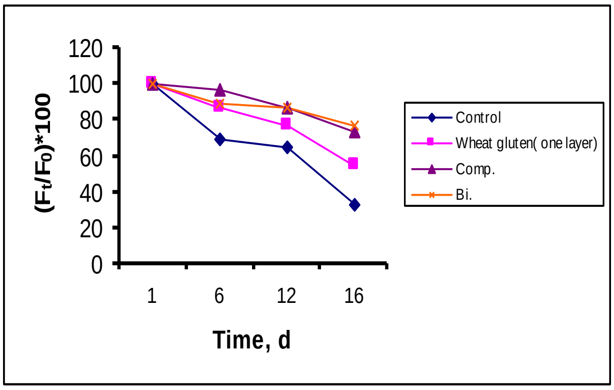
(a)

(b)

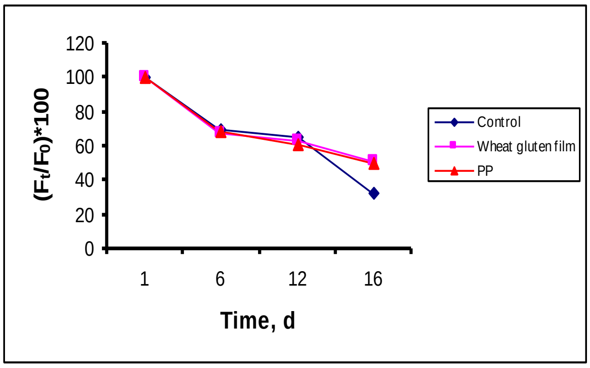
Fig. (2):Effect of gluten-based coatings (a) and films (b) on weight loss of strawberries during storage.

3.5.3. Firmness

Firmness retention was calculated as (F_t/F_0) ×100, at different storage times in days as shown in Fig. 3 (a) and (b). Results in Fig. 3 (a) and (b) show that, all the coating samples, gluten pouch film as well as perforated polypropylene film was statistically significant compared to the control. Firmness of the control sample was gradually decreased during the storage period. Results in Fig. 3 (a) and (b) were statistically analyzed, so, at the end of the experiment (16 days) firmness retention of the wheat gluten coating (one layer) on strawberries (Fig. 3a) was statistically significant which was higher than the wheat gluten pouch film (Fig. 3b). The delay in senescence may be due to the development of an adequate internal atmosphere in coated fruit as observed by Carrilo-Lopez *et al*. (2000). The bilayer and composite coatings showed a good result with respect to the retention of fruit firmness probably because this coating might be slowed down metabolism and prolonged the storage life, an effect was previously observed by El Gaouth *et al*. (1991).



(a)

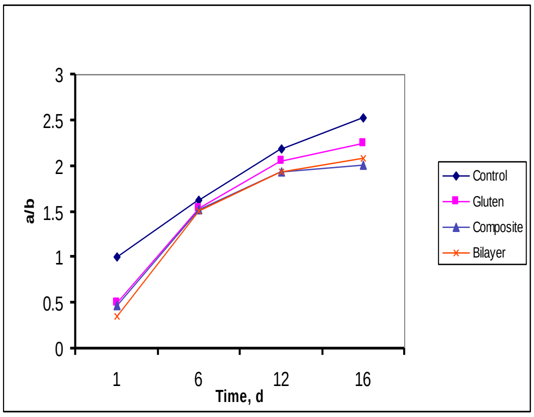


(b)

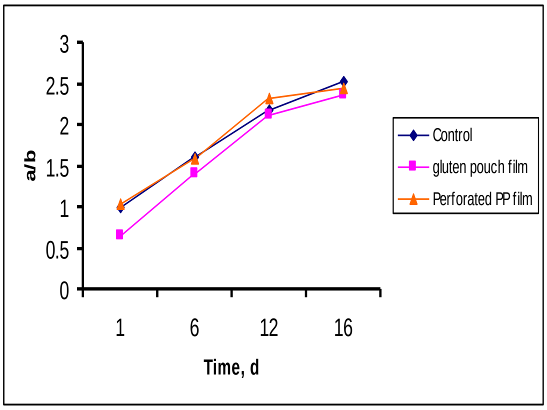
Fig. (3): Effect of coatings (a) and films (b) on firmness retention of strawberries during storage

3.5.4. Surface color development

Color changes during storage of different samples were observed by an increase in a/*b* ratio with an increase in redness (*a*) and a decrease in yellowness (*b*). Results in Fig.(4) a and b, showed that a/*b* ratios were increased with the storage time increases in all treatments. Control sample showed the highest a/b values during storage that were statistically significant in comparison with all of the other treatments. Thus these coatings and films were effective to promote a small delay of surface color development compared with the control treatment, as were previously observed by Tanada-Palmu, and Grosso (2005).



(a)



(b)

Fig. (4): Surface color changes of coated (a) and packed (b) strawberriesduring storage.

3.5.5. Sensory evaluation of the strawberries

Results of sensory evaluation of different strawberrys samples showed significant differences (P <0.05) (Table 5). The bilayer coated fruits as well as the composite coated fruits were superior to the other examined samples for color, brightness, and overall acceptability during all storage periods. Meanwhile, the flavor of bilayer coated strawberry fruits was significantly different (P <0.05) compared with the corresponded fruits coated with composite coating. They show such improve in their texture, as the storage time increased, indicated that, the ability of coating materials to absorb water denote the sence of good texture as mentioned by Tanada-Palmu, and Grosso (2005).

Control strawberry samples showed graduall decrease for all the tested parameters throughout the storage times. Strawberry fruits packed into perforated polypropylene showed significant difference (P <0.05) for their color, brightness and texture during storage time up to 12 days that affected by the surrounded environmental conditions.

Conclusions

Wheat gluten can be used as a source of protein-based biodegradable films and coatings. Different concentrations of glycerol (as plasticizer) influenced the characteristics of wheat gluten films like water vapor and mechanical properties (tensile strength and percent elongation at break). Results showed that the addition of plasticizer generally increased water vapor and solute permeability of the film, and decreased the tensile strength. Gluten based films showed promising as protective coatings materials for perishable foods such as strawberries. Wheat gluten coatings and films extended the shelf life of strawberries and retarded the senescence process compared with strawberries used as a control treatment. The addition of lipids to the gluten coatings composite showed a beneficial effect on firmness retention and reduced weight loss of strawberries. The fruit with the gluten pouch film also had higher firmness retention compared to the control fruit, and reduced the number of infected fruit in comparison with the control fruit. The sensory evaluation of the strawberries showed that fruits with coatings maintained their quality during storage time and the consumers approved the taste and flavor of the different gluten-coated fruits.

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تعبئة وتغليف ثمار الفراولة المبردة (*Fragaria ananassa*) بإستخدام أغشية مصنعة من جلوتين القمح

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ملخص

أستخدم جلوتين القمح في تحضير أفلام صالحة للأكل بغرض استخدامها لتغطية ثمار الفراولة الطازجة بصورة مباشرة (كغطاء ملاصق للثمار) أو غير مباشرة (تغطية العبوة الموجود بها الثمار). واستخدم في تحضير الأفلام والأغطية مادة الجلسرول (كمادة مكسبة للمرونة) بتركيزات مختلفة مع استخدام رقم الاس الهيدروجيني المناسب وهو pH 10 . تم دراسة تأثير استخدام تلك الأفلام والأغطية علي جودة وصلاحية ثمار الفراولة المحفوظة بالتبريد علي درجة حرارة 5^5م. ووجد أن الأفلام المصنعة بأقل تركيز من الجلسرول (20%) تتميز بانخفاض نفاذيتها لكل من بخار الماء والأكسجين. كما تم دراسة بعض الخواص الاخري مثل قوة الشد فوجد أنها سجلت اعلي قيمة عند اقل تركيز من الجلسرول وعلي العكس نجد أنه عند تقدير الاستطالة للفيلم وكذلك ذوبان الفيلم في الماء كنسبة مئوية وجد أنهما سجلا أقل قيمة . وكانت أفضل النتائج للفيلم المصنع من (25%) الجلسرول. وكانت أعلي جودة لثمار الفراولة تلك التي تم تعبئتها في أفلام جلوتين القمح بالمقارنة بمثيلتها المعبأة في البولي بروبلين المثقب وذلك من ناحية جميع الخصائص الطبيعية والحسية مثل تعفن الثمار , تغير لون سطح الثمرة , , الفقد بالوزن , صلابة الثمار , وكذلك التقييم الحسي للثمار. وعند تغطية الثمار بالتركيبات التي تم تصنيعها اعتمادا علي جلوتين القمح تم تطبيقها بعدد مختلف من الطبقات 1) تغطية الثمار بطبقة واحدة من التركيبة المحضرة من جلوتين القمح فقط . 2) تغطية الثمار بطبقة واحدة من جلوتين القمح مضاف له بعض الأحماض الدهنية (استياريك – بالمتيك) بالاضافة الي شمع عسل النحل . 3) تغطية الثمار بطبقتين من التركيبة المحضرة من جلوتين القمح فقط. ووجد أن الثمار المغطاة بطبقتين أظهرت تأثيرا واضحا في الحد من انخفاض صلابة الثمار وكذلك الفقد في الوزن مقارنة بالثمار غير المغطاة طوال فترة التخزين. كما أظهرت النتائج أن تلك التركيبات كان لها القدرة علي تقليل تعفن الثمار مقارنة بالفيلم المصنع من جلوتين القمح . وتم أجراء التقييم الحسي لثمار الفراولة المغطاة بالتركيبات المختلفة المحضرة من جلوتين القمح والتي تم تخزينها علي 5° م طوال فترة التخزين (16 يوما). حيث وجد إن تلك التركيبات حافظت علي جودة الثمار طوال فترة التخزين , بالإضافة إلي احتفاظها بالطعم الطبيعي.

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