Journal of Food Science and Technology (Iran)

Homepage:www.fsct.modares.ir

Scientific Research

Biodegradable film based on mucilage of fenugreek seeds and eggplant skin powder with copper nanoparticles and rosemary essential oil, investigation of its physicochemical properties

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ARTICLE INFO

Article History:
Received:2023/11/2
Accepted: 2024/1/2

Keywords:

edible film,
mucilage,
copper nanoparticles,
rosemary essential oil

DOI: **10.22034/FSCT.21.147.146.**

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ABSTRACT

In this study, mucilage was extracted from fenugreek seeds and essential oil from rosemary. The composite film of fenugreek seed mucilage and eggplant peel powder was prepared with copper nanoparticles (0, 2, 4%) and rosemary essential oil (0, 4, 8%). The physicochemical properties of the prepared films were investigated. According to the obtained results, with the increase of copper nanoparticles and rosemary essential oil, the thickness and antioxidant of the film increases. Humidity, water vapor permeability and solubility of the film decrease with the increase of copper nanoparticles and rosemary essential oil. Also, with the increase of copper nanoparticles and rosemary essential oil, the L* color indices increased and the brightness of the layers decreased significantly. Also, with the increase of copper nanoparticles, the color indices a* increased, but b* decreased. Also, with the increase of rosemary essential oil, the a* color indices have decreased, but the b* factor has increased. The results of antimicrobial activity showed that the addition of copper nanoparticles and rosemary essential oil made the film active against Staphylococcus aureus. Conclusion: The addition of copper nanoparticles and rosemary essential oil to edible films based on fenugreek seed mucilage and eggplant skin powder improved the thickness and antioxidant, solubility, moisture and permeability to water vapor, as well as weakening the brightness.

1. Introduction

Due to the increase in the production and consumption of petroleum polymers and plastics in human daily life, diseases caused by food poisoning have become a great threat to human health. environment and have contributed to the emergence of the packaging industry. Since the major part of the packaging industry is plastic, the packaging industry can be linked to petroleum products [1 2]. Therefore, the ever-increasing population growth, pollution caused by petroleum derivatives packaging materials and problems caused by different methods of disposing of these pollution materials, including burning, burial and recycling, have drawn more attention to bio-polymers and bio-packaging. Biodegradable films and coatings are a good alternative to synthetic films in the packaging industry due to their compatibility with the environment and low dependence on non-renewable resources, and have attracted the attention of many researchers [3 4].Synthetic plastics used for packaging. Different types of food cause serious environmental problems. The environmental effects of plastic consumption in the food industry have encouraged the packaging industry to produce packaging from renewable materials [5 6]. Biodegradable packaging protects food products against mechanical, physical, and chemical damage and prevents their quality loss. It can also prevent microbial activity as an antimicrobial carrier in the form of antimicrobial packaging and increase the shelf life of food products [7 8]. In recent years, many studies have been conducted in the field of replacing synthetic polymers with biodegradable polymers, especially for food packaging.Most of the disadvantages and problems of synthetic polymers have not been raised for biopolymers due to their biodegradability in nature, and this has caused many researchers in the study of food packaging to use a variety of biopolymers to make biopackaging. consider degradable [9 10]. Eggplant is the common name for a plant from the Solanaceae family belonging to Southeast Asia. The scientific name of this plant is Solanum and its fruit is known by the same name. Depending on the phenotype of the plant, the eggplant fruit has purple, green or white colors, the most common of which is dark purple and is widely consumed among vegetables all over the world. One of the characteristics of the chemical composition of the fruit of this plant is the high amount of water in it, which, along with the low calorie content, has attracted the attention of nutrition experts. Studies have shown that anthocyanin in the fruit of the plant has an antioxidant effect. Among the vitamins found in eggplant, we can mention group B vitamins, especially 1B and 6B, vitamins A and C, and various minerals such as calcium, phosphorus, sulfur, magnesium, potassium, copper, and iron. In addition to the mentioned vitamins and minerals, eggplant has phytonutrients that have great antioxidant properties. Phytonutrients in eggplant include phenolic components such as caffeic and chlorogenic acid and flavonoids such as nasunin. Phenolic components have anti-cancer, anti-bad cholesterol and anti-viral properties [11]. Fenugreek seeds, as the most important medicinal part of the plant, have many uses. Saponins, mucilage compounds (28%), alkaloids and fixed oils containing unsaturated acids (10 6%) constitute the effective medicinal substances of fenugreek seeds.The most important steroidal sapogenins obtained from fenugreek saponins include diosgenin and yamogenin. It is an important economic source for the production of mucilage (galactomannan), trigonelline and diosgenin in the pharmaceutical industry [12 13]. Fenugreek seeds have antidiabetic properties, pain relief and effects such as anticancer, reducing cholesterol and blood sugar in traditional medicine [11]. In Iran, fenugreek seeds are used as a tonic and reduce blood sugar [14]. Nanotechnology is one of the most important and fastest growing sectors of advanced technology. Products containing nanoparticles can be used in various industrial, medical, personal and military applications. Nanocomposite is a composite material in which at least one of its phases has nanoscale dimensions (between 1 and 100 nm) [15 16]. Nanocomposites are new alternatives to the traditional methods of improving the properties of polymers. Nanocomposites are currently used for non-alcoholic beverage and food packaging due to their improved thermal properties, strength and conductivity. Mucilages have a wide range of applications: in food and nutraceuticals as structuring, gelling, texture, and film forming, in pharmaceuticals as binders and disintegrants for drug delivery systems, and in cosmetics as

[DOI: 10.22034/FSCT.21.147.146]

stabilizers. They have also attracted a lot of interest in the textile and paper industries, and they can be used in the production of paints. Copper nanoparticles are used in various fields such as biomedicine, pharmaceuticals, bioremediation, molecular biology, bioengineering, genetic engineering, dye decomposition, catalysts, cosmetics and textiles.The structural properties and biological effects of copper nanoparticles have promising effectiveness in the field of biological sciences. The antimicrobial effects of copper nanoparticles have been investigated in various studies [17]. Rosemary is one of the oldest known medicinal plants that has been used for centuries to strengthen memory and brain activity [18]. The ingredients in rosemary leaves are: luteolin, genquanin, tannin, resin, pasonin, fat, carbohydrate, fiber, salts and vitamins. Rosemary essential oil is an aromatic substance that is used in the perfume industry, especially for men's colognes. Rosemary essential oil dilates skin vessels and increases blood supply, resulting in better nutrition of hair follicles, leading to the growth and transformation of fluffy hair into thick hair. The products containing this essential oil cause the scaling of the scalp (dandruff).Rosemary essential oil is a stimulating oil, whose effect on the central nervous system is very prominent. Also, mountain wreath essential oil is used in the production of medicines to regulate blood circulation, anti-swelling and pain relief and to relieve rheumatism. Therefore, the essential oil of this plant is also used in massage therapy [19]. According to the investigations, there has been no research on the effect of copper nanoparticles and rosemary essential oil on edible films prepared from mucilage of fenugreek seeds and eggplant skin powder. The purpose of this research is to investigate the effect of copper nanoparticles and rosemary essential oil in different concentrations on the physical and chemical properties of edible films prepared based on fenugreek seed mucilage and eggplant skin powder.

2- Materials and methods

2-1- Materials

Mucilage was obtained using fenugreek seeds and essential oil extracted from rosemary plant, zero valence copper nanoparticles with a purity of 99% and skin of eggplant waste. Was used. 99% methanol, glycerol, silica gel, and other chemicals and solutions were obtained from Merck (Germany) and Sigma-Aldridge (USA) and were used without further purification.

2-2 eggplant skins

In this research, eggplant skin was prepared from the wastes of ready-made food factories located in the industrial town of Ajabshir city, washed and dried by a vacuum oven at a temperature of 40 degrees Celsius and turned into small pieces using an electric grinder and used in dishes. It is kept dark.

2-3- The method of preparing mucilage from fenugreek seeds

Fenugreek seeds were mixed with distilled water at a ratio of 1:20 and first exposed to ultrasonic waves at a temperature of 20°C and then placed on a magnetic stirrer at a temperature of 50°C for 2 hours. Then the entire contents were passed through a fabric filter. The remaining seeds on the cloth strainer were again mixed with a smaller proportion of distilled water and passed through the cloth strainer after stirring for 1 hour. Then the mixture obtained from the previous step was centrifuged for 10 minutes at a speed of 4000 rpm. The mucilage obtained from the previous step is dried using an oven at a temperature of 40 degrees Celsius and stored in a zipped bag [20].

2-4- Preparation of essential oil from rosemary plant

Rosemary plant essential oil was obtained by distillation with water using a Cloninger machine. In this way, the ground rosemary plant was poured into the balloon and about three times of distilled water was added. By closing the connections of the balloon and the refrigerant and showing the flow of cold water related to the refrigerant and heating the balloon, the essential oil was extracted and the water was extracted with anhydrous sodium sulfate [21].

2-5- Production of films

First, 1 gram of mucilage of fenugreek seeds and eggplant peel powder was poured into 70 ml of distilled water at a ratio of 1:1 and stirred using a magnetic stirrer at a temperature of 60 degrees Celsius and a speed of 500 rpm. And different percentages of copper nanoparticles (0, 2, 4%) and rosemary essential oil (0, 4, 8%) were dissolved in 30 ml of distilled water and added to the solution. After adding 25% glycerol to the solution, pH was adjusted to 7 using NaOH solution. The solution was poured into the Falcon and centrifuged. The resulting supernatant solution was poured into the plate and after 48 hours the films were dried at room temperature, then the dried films were stored in zipped bags [22].

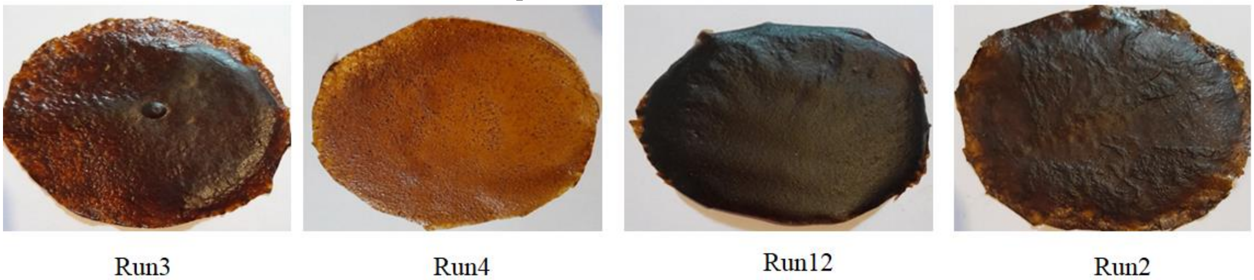

Fig 1: An image of the prepared films

2-6- Characteristics of films

2-6-1- Film thickness measurement

The thickness of the prepared films was measured using a digital micrometer with an accuracy of 0.001 mm. At least 5 different points were measured in each film and the average numbers obtained were reported and used in different experiments.

2-6-2- Humidity measurement

To check the moisture level, first, the films were cut into 3x3 cm2 dimensions and weighed with a scale (initial weight) and placed in a desiccator containing silica gel for 24 hours. Then the films are weighed again (final weight). Then, using the following formula, the amount of moisture was obtained [22].

$$Moisture(\%) = \frac{Wi - Wf}{Wi} \times 100$$

In this regard, Wi is the initial weight and Wf is the final weight

2-6-3-Measurement of antioxidant properties

25 mg of each film was dissolved in 4 mL of water for 2 min. Then 2 ml of the film extract solution is mixed with 0.2 ml of 1 mM DPPH[1] methanol solution. The mixture was vortexed well at 500 rpm for 1 min. After 30 minutes of storage in a dark place, the decrease in absorbance at the wavelength of 517 nm was calculated using spectrophotometry with the following formula [22].

$$A(\%) = \frac{Ab - As}{Ab} \times 100$$

Ab: Absorption rate of the control sample
As: sample absorption rate

2-6-4- Measurement of solubility in water

To measure solubility in water, first each film sample (3x3 cm2) was weighed and placed in a dryer, and then accurately weighed with a digital scale. Then, the films are placed in an Erlenmeyer flask for 6 hours, and every 20 minutes, 50 ml of deionized water is poured into it and stirred slowly, and then the solution is filtered through a sieve. In the next step, the filter paper along with the film was kept in an oven at 40°C for 24 hours and weighed again [22].

$$Solubility(\%) = \frac{M1 - M2}{M1} \times 100$$

M1 is the initial weight of the sample and M2 is the weight of the sample after drying.

2-6-5- Measurement of film permeability

Permeability is defined as the passage of water molecules through the film and was measured at a temperature of 25 °C and a relative humidity gradient of 100.50% according to the ASTM E96-05 method. Films with specific thicknesses were stored for 48 hours at a relative humidity of 50% and a temperature of 25°C before testing. To measure water vapor permeability, a vial with a diameter of 2 cm and a height of 10 cm was used, which had a hole with a diameter of 8 mm. For this purpose, 3 grams of calcium sulfate were weighed in containers to remove moisture, and then a piece of film was placed inside the cap and closed on the vial. Then the containers were weighed and placed in a desiccator containing 1 liter of distilled water at a temperature of 23 degrees Celsius, and then the containers were weighed every 24 hours for a week. Water vapor permeability was calculated according to the following equation [22].

$$WVP = \frac{WVTR \times T}{P(R_1 - R_2)}$$

1-2-2-Diphenyl-1-picrylhydrazyl

[DOI: 10.22034/FSCT.21.147.146]

where WVTR is the constant water vapor transfer rate (g/m2.h), T is the film thickness (mm), P is the partial water vapor pressure at 25 degrees Celsius (2.642 kPa), R1 is the relative humidity in the desiccator (100%) and R2 The relative humidity in the container is (0%)

2-6-6- Measurement of color characteristics

Color parameters (Hunter L, a, b) were measured using the Hunter lab system (Colorimeter Minolte CR-400). In order to calibrate the device, a standard white screen was used to measure the color of the films. The factors determined in this device include L or film brightness (0 to 100), a green-red (-80 to 100) and b blue-yellow (-80 to 70) [22].

2-6-7- Investigation of antimicrobial properties

In the agar diffusion method, films with a diameter of 15 mm were cut into disks and placed on Mueller Hilton agar culture medium and plates containing Escherichia coli and Staphylococcus aureus. Then the plates were kept for 24 hours in a greenhouse with a temperature of 37 degrees Celsius. Then, the diameter of the lack of growth was measured with a caliper [22].

2-7-Analysis of statistical analysis

In this study, response surface statistical method and central composite statistical design were used to investigate the effect of two variable factors of copper nanoparticle percentages and rosemary essential oil on the physicochemical properties of the prepared films. The statistical analysis of the data was done at the 95% probability level using Design Expert-10 software.

Table 1: Table of prepared films

Film	A: NP (%)	B: Essential oil (%)
F1	2	**4**
F2	4	**8**
F3	0	**0**
F4	0	**8**
F5	2	**4**
F6	4	**4**
F7	2	**0**
F8	2	**4**
F9	2	**4**
F10	0	**4**
F11	2	**1**
F12	4	**0**
F13	2	**2**

3- Results and Discussion

3-1- Thickness

The film thickness measurement results are shown in Figure 2. As can be seen, the thickness of the layers varies from 0.370 to 0.735 mm and with the increase in the percentage of copper nanoparticles and rosemary essential oil, the thickness of the layers has increased. The reason for this increase in thickness can be attributed to the concentration of small essential oil particles in the film, which has a small effect on the thickness of the prepared films and increases its thickness by a small amount. In addition, the addition of essential oil creates a non-uniform structure with pores, which indicates an increase in thickness [23]. The reason for increasing the thickness of the layers by adding copper nanoparticles and rosemary essential oil is to increase the dry matter of the layers and also to absorb water in the single layer area by this hydrocolloid compound. that the layers have less moisture when drying. And the sum of these changes increases the thickness of the produced films [24]. which is consistent with the results of Abdul Sattari et al [25].

Thickness (mm)= 0.435 +0.096 * A +0.087 * B +0.075 *A*B +0.027 * A^2 +0.025 *B^2

(R^2 =0.973; AdjR^2 =0.954)

A: Nano B: Essential oil

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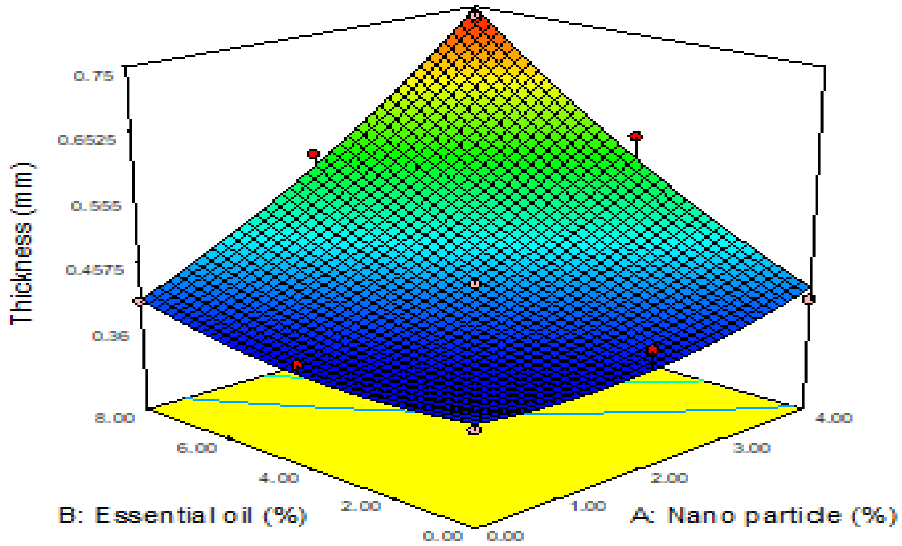

Figure 2: The three dimensional figure of the film thickness of fenugreek seed mucilage and eggplant peel powder with copper nanoparticles and rosemary essential oil.

3-2- Humidity

The humidity level is a parameter related to the occupied volume, it depends on the water molecules in the microstructure of the film. Water resistance is one of the important characteristics of biodegradable and edible films because it indicates their efficiency in protecting food with high water activity or fresh and frozen materials. The effect of the percentage of copper nanoparticles and rosemary essential oil on humidity is shown in Figure 3-. The mathematical equation shows the relationship between independent variables and humidity and regression coefficients. The amount of moisture absorption depends on the amount of empty spaces available for the penetration of water molecules and the degree of hydrophilicity of the polymer. Mucilages are naturally hydrophilic and increase the rate of moisture absorption in the film. They have hydroxyl groups in their structure and therefore are considered as hydrophilic substances.Moisture absorption of a film depends on the hydrophilic property of that polymer or biopolymer and then on the presence of holes and empty spaces between the chains. According to the three-dimensional shape of the moisture content of the film, mucilage of fenugreek seeds increases the moisture content of the film, but the addition of copper nanoparticles and rosemary essential oil reduces the moisture content of the film. The addition of copper nanoparticles through hydrogen and covalent bonds to the protein network reduces the free hydrogen groups available to form hydrophilic bonds with water and ultimately reduces the water activity and wettability of the protein film [26]. By creating electrostatic forces through oxygen atoms, copper nanoparticles engage H and OH - groups with chains of fenugreek seed mucilage and eggplant skin powder and block the entry of H2O molecules into the polymer structure. and reduces humidity.By occupying the space between the polymers in fenugreek seed mucilage water and eggplant skin powder, copper nanoparticles and rosemary essential oil do not allow water molecules to be trapped, and maybe that is the reason why this has reduced the percentage of moisture in the film, which is consistent with the results of Khakpour et al. has [22].

Moisture (%)= 19.887 -1.625 *A -3.547*B

(R^2 =0.916 ; AdjR^2 =0.899)

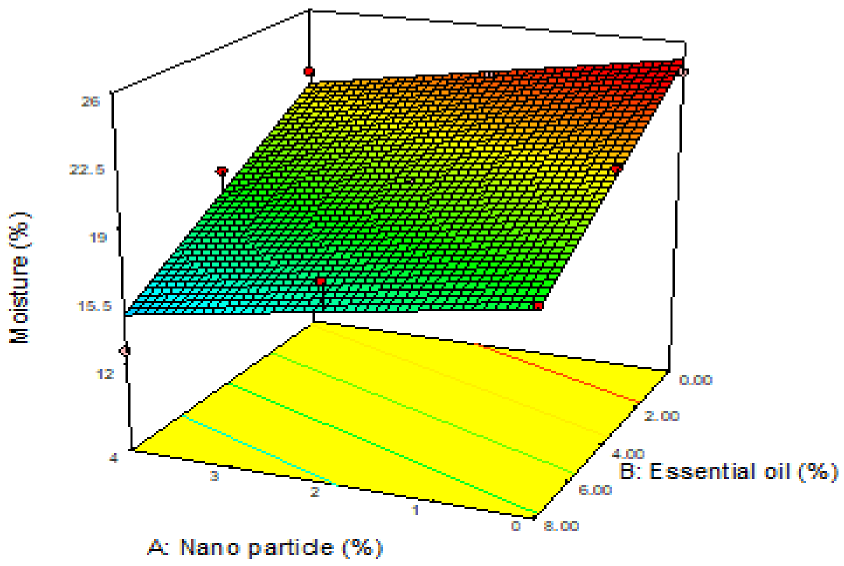

Figure 3: The three dimensional figure of the moisture content of the mucilage film of fenugreek seeds and eggplant skin powder with copper nanoparticles and rosemary essential oil.

3-3- antioxidant

Antioxidant properties are one of the most important features of active layers that are considered in the packaging of food products sensitive to oxidation. Active antioxidant films can easily increase the shelf life of food products such as oils by absorbing oxidizing agents. Antioxidants such as essential oils and copper nanoparticles extinguish their contact with oxidizing agents and protect food from the oxidation process. The effect of the percentage of copper nanowires and rosemary essential oil on the antioxidant property is shown in Figure 3.3. The mathematical equation shows the relationship between independent variables and antioxidant properties and regression coefficients. According to Figure 4, with the increase of copper nanoparticles and rosemary essential oil, the antioxidant properties increased significantly ($p<0.05$).DPPH radical is a stable free radical with a central nitrogen atom, which changes the color of DPPH from purple to yellow in the presence of antioxidants by reducing and producing a stable molecule. The antioxidant property of rosemary has been confirmed in various researches, some of the compounds of this plant have anti-cancer effects and some enzyme inhibition effects, the presence of fat-reducing compounds and flavonoids with strong antioxidant activity have been reported in this plant, so according to The antioxidant structure of rosemary, the increase in the antioxidant property of the film was expected with the increase of rosemary essential oil. Due to its high surface-to-volume ratio, copper nanoparticles have the ability to react with free radicals and physically absorb them, and they can easily deactivate free radicals [27]. which is consistent with the results of Khakpour et al [22].

Antioxidant activity (%)= 36.365 +4.865 *A +17.306 *B -2.284*A*B +2.020*A^2 -7.143*B ^2

(R^2 =0.997; AdjR^2 =0.995)

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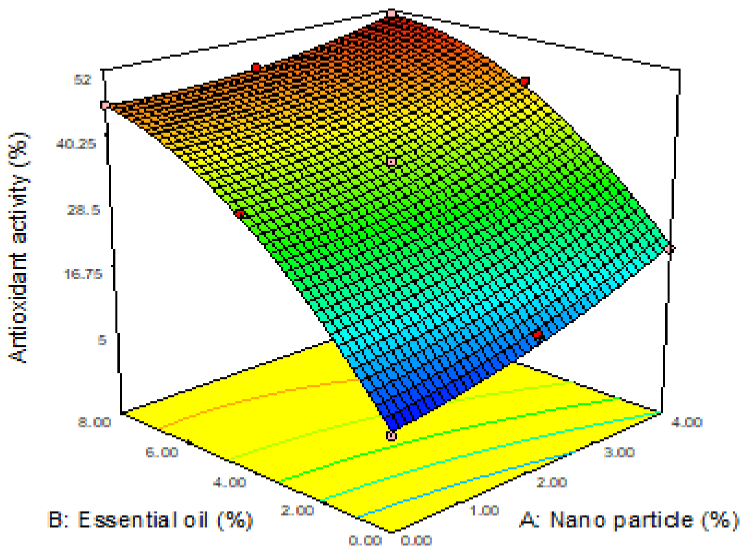

Figure 4: The three dimensional figure of the antioxidant film of fenugreek seed mucilage and eggplant skin powder with copper nanoparticles and rosemary essential oil.

3-4- Solubility

The effect of the percentage of copper nanowire and rosemary essential oil on solubility is shown in Figure 5. The mathematical equation shows the relationship between independent variables and solubility and regression coefficients. Water resistance is one of the important features of biodegradable and edible films. Because it shows their effectiveness in protecting food with high water activity or frozen food. Solubility refers to the percentage of insoluble materials in the film. The lower the percentage of this variable, the better the film will be because packaging films with such characteristics can be resistant to high humidity conditions [26]. According to Figure 5, the solubility of the film decreased significantly ($p<0.05$) with the increase of copper nanoparticles in rosemary essential oil.As can be seen from the results, the solubility of nanocomposite films decreases with the increase of copper nanoparticles and rosemary essential oil. Copper nanoparticles and rosemary essential oil occupy the space between the polymers in the mucilage of fenugreek seeds and eggplant skin powder and do not allow water molecules to be trapped. And maybe that is the reason why the essential oil decreased the solubility percentage of the film [28].

Solubility (%)= 31.582 -2.076 *A -5.029 *B
(R^2 =0.930; AdjR^2 =0.916)

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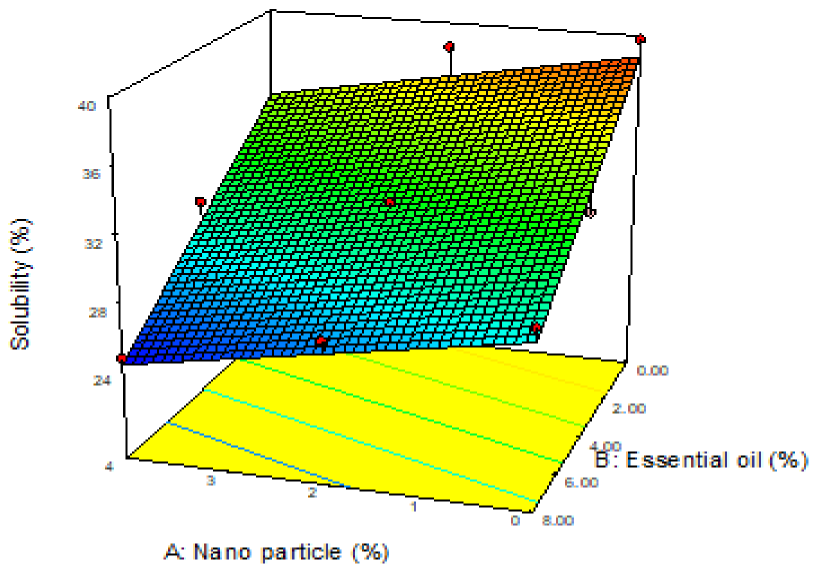

Figure 5: The three-dimensional figure of solubility of fenugreek seed mucilage film and eggplant peel powder with copper nanoparticles and rosemary essential oil.

3-5- Permeability

The effect of the percentage of copper nanoparticles and rosemary essential oil on water vapor permeability is shown in Figure 6. The mathematical equation shows the relationship between independent variables and water vapor permeability and regression coefficients. As it is known, the materials used in packaging must have a minimum permeability to water vapor (WVP) in order to prevent the exchange of moisture between the environment and the food, the packaging film must prevent the penetration of water vapor into the packaging of moisture-sensitive food effectively control and minimize microbial spoilage [29]. According to Figure 6, with the increase of copper nanoparticles and rosemary essential oil, the permeability of the film to water vapor decreased significantly ($p<0.05$), which is consistent with the results of Ghasemlou et al. [30]. Rosemary essential oil is due to hydrogen and covalent bonds between fenugreek seed mucilage network and eggplant skin powder and these polyphenolic compounds.These bonds may limit the hydrogen groups to form hydrophilic bonds with water and thus lead to a decrease in the permeability of the film for water. Also, nanoparticles fill the empty spaces of the polymer film and do not allow water molecules to pass through. Copper nanoparticles also probably prevent the passage of water molecules by filling the polymer spaces and reduce the WVP, which is consistent with the results of Farajpour et al [31].

$$WVP\ (g/Pa.m.s) = 0.004 - 0.000\ {*}A - 0.001\ {*}B + 0.000{*}A{*}B + 8.793\ {*}A^2 + 0.000\ {*}B^2$$

($R^2 = 0.987$; $AdjR^2 = 0.979$)

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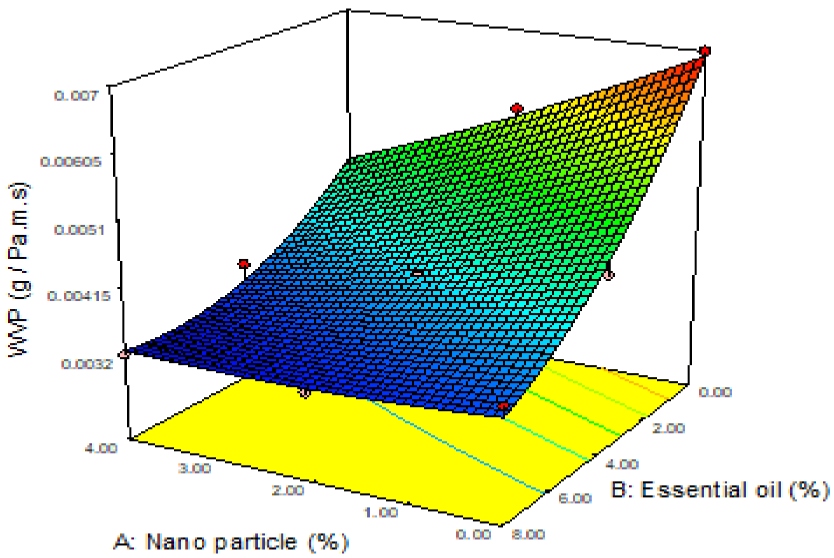

Figure 6: The three dimensional figure of water vapor permeability of fenugreek seed mucilage film and eggplant skin powder with copper nanoparticles and rosemary essential oil.

3-6- Color features

The effect of the percentage of copper nanoparticles and rosemary essential oil on L, a, b is shown in Figure 7. The mathematical equation shows the relationship between the independent variables L, a, b and the regression coefficients. Research in the field of food color and factors affecting it is still an important part of research in the field of food [32]. The color and transparency of packaging films play an important role in their appearance and acceptability. Usually, in the packaging of most food products, it is preferred that the polymer used is colorless, completely transparent and shows the appearance characteristics of the packaged product. The color parameter L provides a measure of lightness/darkness. The color parameter a provides a measure of redness/greenness, the color parameter b provides a measure of yellowness/blueness. L values range from 0 to 100 as an indication of dark to light.The higher the amount of compound L, the higher the brightness, according to the shapes, increasing the copper nanowire decreases the brightness of the films due to its dark color, and rosemary essential oil decreases the brightness of the films due to its yellow color. Based on numerous studies, there are different results related to the effect of different nanoparticles on the color indices of nanocomposite films, which can be due to the different properties and characteristics of nanoparticles. With the increase of copper nanoparticles, the amount of a increased significantly ($p<0.05$), but the amount of b decreased. Also, with the increase of rosemary essential oil, the amount of a decreased significantly ($p<0.05$), but the amount of b increased. which is consistent with Zulfi et al.'s results [33].

$$L^* = 42.202 - 11.647 A + 5.767 B - 1.359 AB + 6.486 A^2 - 0.745 B^2$$

($R^2 = 0.997$; $AdjR^2 = 0.995$)

$$a^* = 5.923 + 4.528 A - 3.041 B$$

($R^2 = 0.788$; $AdjR^2 = 0.746$)

$$b^* = 11.213 - 13.266 A + 4.090 B + 0.005 AB + 6.117 A^2 - 1.147 B^2$$

($R^2 = 0.978$; $AdjR^2 = 0.963$)

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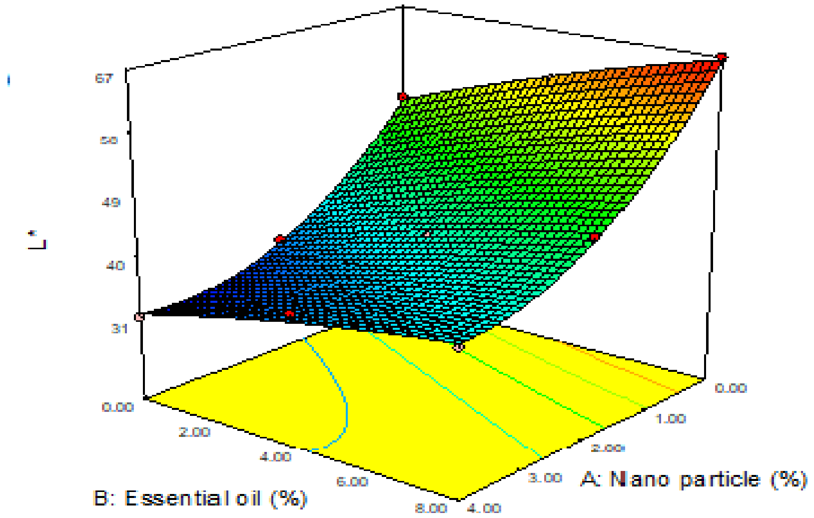

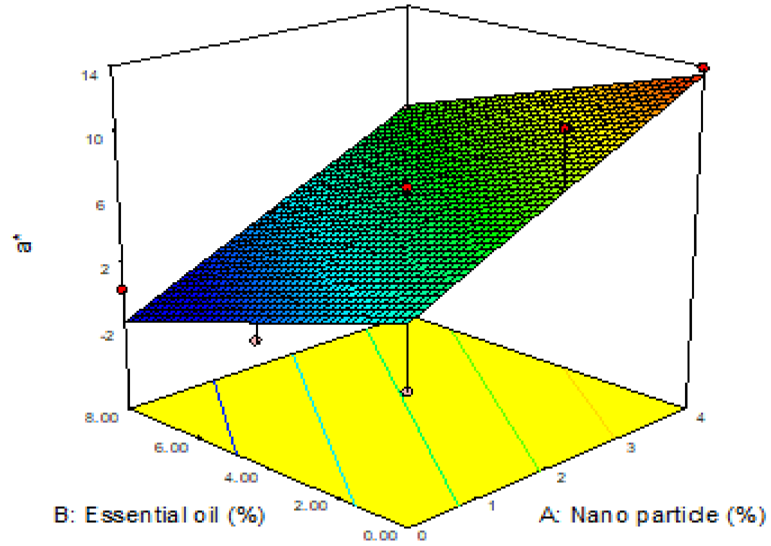

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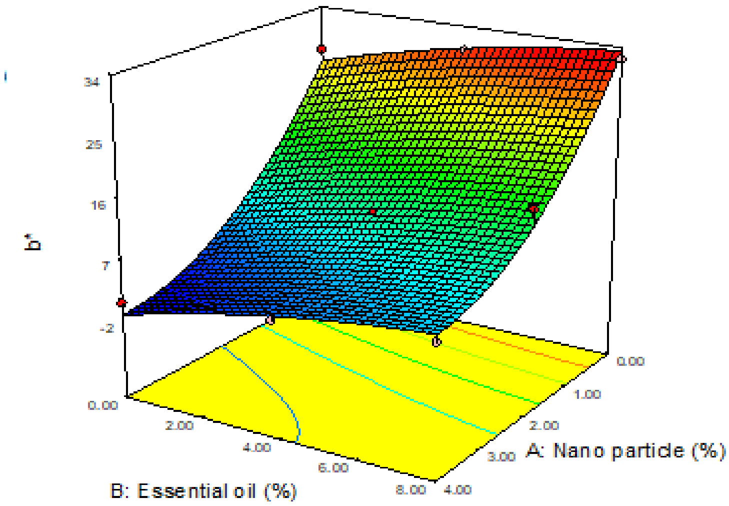

Figure 7: L,a,b three dimensional figure of fenugreek seed mucilage film and eggplant skin powder with copper nanoparticles and rosemary essential oil.

3-7- Antimicrobial

The antimicrobial activity of the films was determined by measuring the halo of non-growth of two types of gram-negative and gram-positive bacteria using a caliper (with an accuracy of 0.001 mm). The larger the diameter of the halo of no growth, the better the desired film gives the antimicrobial power of that film). As it is known, the mentioned films prevented the growth of Staphylococcus aureus. By increasing the amount of copper nanowire and rosemary essential oil, the diameter of the growth halo has increased. Therefore, it can be said that films supported with these compounds can act as an active packaging against microorganisms. In general, the inhibitory property of films containing copper nanoparticles and rosemary essential oil against Gram-positive microorganisms (S. aureus) is higher than Gram-negative types (E.coli). Escherichia coli are Gram-negative that have an outer lipopolysaccharide layer and additional partial membrane components in addition to an intact plasma membrane.The surrounding of its cell potentially has more buffer capacity and hydrophobicity and therefore it can create an unfavorable environment for simple phenols to exert their excessive acidification effect and thus increase the sensitivity of these bacteria to phenolic compounds. decreases. The general result is that the effect of the above substances on gram positive bacteria is more than gram negative. This result is consistent with the results of Shan et al. [34]. They concluded that Escherichia coli is the most resistant bacterium and Staphylococcus aureus is the most sensitive bacterium to medicinal plants, that gram positives are more sensitive than gram negatives due to the structure of the cell wall and outer membrane. The cause of this phenomenon is the difference in the cell wall structure of these two types of bacteria.The main composition of the cell wall of Gram-positive bacteria is peptidoglycan with a small amount of protein; However, the cell wall of Gram-negative bacteria is more complex despite being less thick and contains different polysaccharides, proteins and lipids in addition to peptidoglycan. Also, the cell wall of Gram-negative bacteria has an outer membrane that covers the outer surface of the wall. The combination of these factors increases the resistance of Gram-negative bacteria compared to Gram-positive bacteria [35]. Plants can produce antimicrobial compounds to protect against biological attacks, which can be essential for resistance to microbial infection.Phenolic compounds are the main group responsible for the antimicrobial activity of most plant essential oils. Phenolic compounds are found in many plant species. These compounds seem to defend plants against invading pathogens, including bacteria, fungi, and viruses. have a role. Phenolic compounds potentially disrupt the function of the bacterial cell membrane, which delays the growth and proliferation of bacteria. Phenolic compounds are also involved in adhesion binding, protein and cell wall binding, enzyme inactivation, and cell wall or DNA interference during pathogen inactivation [36].

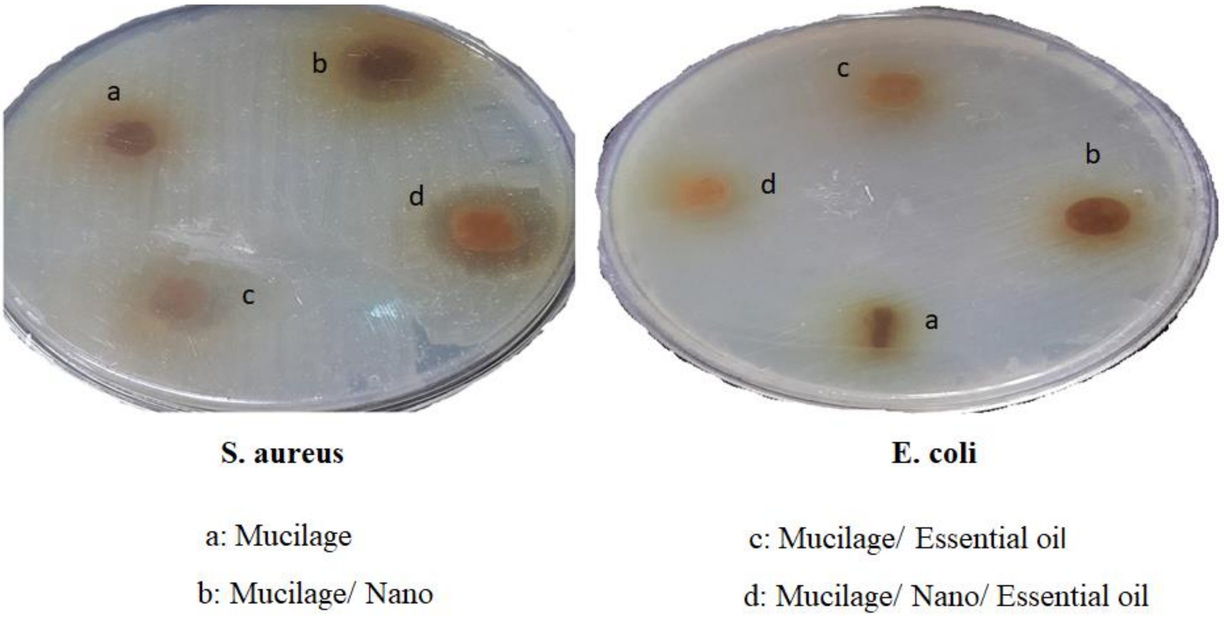

Figure 8: Growth halo diameter (mm)

4- Conclusion:

The biocomposite of fenugreek seed mucilage and eggplant skin powder, copper nanoparticles and rosemary essential oil as a biodegradable film with physical properties has a high potential as a coating. Rosemary essential oil is also rich in antioxidant compounds. Copper nanoparticles and rosemary essential oil in combination with fenugreek seed mucilage and eggplant skin powder can be used as a suitable coating for food. The effect of edible biocomposite coating of fenugreek seed mucilage and eggplant skin powder with copper nanoparticles and rosemary essential oil was investigated in terms of physicochemical properties. Despite all the advantages of fenugreek mucilage biopolymer and eggplant skin powder in the production of biodegradable films, poor mechanical properties and its sensitivity to water are the main obstacles to the widespread use of this biopolymer in the packaging industry.For this purpose, fenugreek seed mucilage film and eggplant skin powder with copper nanoparticles and rosemary essential oil were used.

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سایت مجله: www.fsct.modares.ac.ir

مقاله علمی_پژوهشی

فیلم زیست‌تخریب پذیر بر پایه موسیلاژ بذر شنبلیله و پودر پوست بادمجان با نانوذرات مس و اسانس رزماری بررسی خواص فیزیکوشیمیایی آن

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اطلاعات مقاله

تاریخ های مقاله :

تاریخ دریافت: ۱۴۰۲/۸/۱۱

تاریخ پذیرش: ۱۴۰۲/۱۰/۱۲

کلمات کلیدی:

فیلم خوراکی،

موسیلاژ،

نانوذرات مس،

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DOI: 10.22034/FSCT.21.147.146.

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چکیده

در این مطالعه موسیلاژ از بذر شنبلیله و اسانس از رزماری استخراج شد. فیلم مرکب موسیلاژ بذر شنبلیله و پودر پوست بادمجان با نانوذرات مس (۰، ۲، ٤ ٪) و اسانس رزماری (۰، ٤، ۸ ٪) تهیه شد. خواص فیزیکوشیمیایی فیلم‌ها تهیه شده بررسی شد. مطابق نتایج به دست آمده با افزایش نانوذرات مس و اسانس رزماری، میزان ضخامت و آنتی‌اکسیدانی فیلم افزایش می‌یابد. رطوبت، نفوذپذیری بخار آب و حلالیت فیلم با افزایش نانوذرات مس و اسانس رزماری کاهش می‌یابد. همچنین با افزایش نانوذرات مس و اسانس رزماری، شاخص‌های رنگ L^*، افزایش یافته و روشنایی لایه‌ها به‌طور معنی‌داری کاهش یافت. همچنین با افزایش نانوذرت مس، شاخص‌های رنگ a^*، افزایش یافته ولی باعث کاهش b^*، شده. همچنین با افزایش اسانس رزماری، شاخص‌های رنگ a^*، کاهش یافته ولی باعث افزایش فاکتور b^*، شده است. نتایج فعالیت ضدمیکروبی نشان داد که افزودن نانوذرات مس و اسانس رزماری باعث فعالیت فیلم علیه *استافیلوکوکوس اورئوس* شد. نتیجه‌گیری: افزودن نانوذرات مس و اسانس رزماری به فیلم‌های خوراکی بر پایه موسیلاژ بذر شنبلیله و پودر پوست بادمجان سبب بهبود ضخامت، آنتی‌اکسیدانی، حلالیت، رطوبت و نفوذپذیری به بخار آب، همچنین تضعیف روشنایی گردید.