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Effectiveness Comparison of Polysaccharides, Proteins, and Lipids as Composite Edible Coatings on the Quality of Food Products

Comparación de la Efectividad de Polisacáridos, Proteínas y Lípidos como Recubrimientos Compuestos Comestibles en la Calidad de los Productos Alimenticios

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ABSTRACT

Background: This research was motivated by the complaints of tomato farmers about their crops that quickly rotted before being sold, as well as the many research results (raw materials and methods) that edible coating films could not be applied optimally. **Objectives:** The research was a practical recommendation by comparing the effectiveness of raw materials (polysaccharides, proteins, and lipids) with the dipping and spray methods. **Materials and methods** used in the comparison process were the application of Structural Equation Modeling (SEM) with the Partial Least Square (PLS) approach. **Results:** Dipping has a strong effect ($f^2 \geq 0.35; p<0.05$), while spray had a moderate effect ($f^2: 0.15\text{-}0.35; p<0.05$). Thus, the role of dipping as a mediator was more dominant than spray. Compared to proteins and lipids, polysaccharides had the best effectiveness ($\beta: 0.460\text{-}0.584; f^2: 0.15\text{-}0.35; p<0.05$). **Conclusion:** the three ingredients improved the quality of tomatoes, and the dipping method was easier to apply by farmers than the spray method, which had many obstacles in its application.

Keyword: Edible coating film, Dipping, Spray, and Structural Equation Modeling (SEM)

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RESUMEN

Antecedentes: esta investigación está motivada por las quejas de los productores de tomate sobre sus cultivos que se pudren rápidamente antes de ser vendidos, así como por los muchos resultados de la investigación (materias primas y métodos) de que las películas de recubrimiento comestibles no se pudieron aplicar de manera óptima. **Objetivos**: La investigación consiste en recomendaciones prácticas mediante la comparación de la eficacia de las materias primas (polisacáridos, proteínas y lípidos) con los métodos de inmersión y aspersión. **Métodos:** El método utilizado en el proceso de comparación es la aplicación del modelo de ecuaciones estructurales (SEM) con el enfoque de mínimos cuadrados parciales (PLS). **Resultados:** La inmersión tiene un efecto fuerte ($f^2 \geq 0,35$; *p<0,05*), mientras que la pulverización tiene un efecto moderado (f^2: 0,15-0,35; *p<0,05*). Por lo tanto, el papel de la inmersión como mediador es más dominante que el del rociado. Los polisacáridos tienen la mejor eficacia (β:0,460-0,584; f^2: 0,15-0,35; *p<0,05*) en comparación con las proteínas y los lípidos. **Conclusión:** es que los tres ingredientes pueden mejorar la calidad de los tomates, y el método de inmersión es más fácil de aplicar por los agricultores que el método de aspersión, que tiene muchos obstáculos en su aplicación.

Palabra clave: película de recubrimiento comestible, inmersión, pulverización y modelado de ecuaciones estructurales (SEM)

INTRODUCTION

The background of this research was based on the complaints of many farmers in Indonesia against tomatoes that quickly rot before they are sold out. This condition resulted in farmers selling their crops immediately before the spoilage occurred. Paying attention to this phenomenon, researchers offer a preservation process with a packaging method that can be eaten, namely edible coating film (ECF). The number of edible coating research references will assist in selecting edible coating raw materials, application methods, and the results of the preservation process. This research focused on applying previous research if it is widely applied, not just a theory or concept. This research helps in selecting raw materials and methods that are cheap and easy to apply.

So far the raw materials often used are polysaccharides, proteins, and lipids. Polysaccharide-based materials include starch, cellulose, pectin, alginate, carrageenan, chitosan, pullulan, gellan gum, and xanthan gum [1–4]. A mixture of two polysaccharides (chitosan and pectin) can increase the shelf life of fruit and vegetable products [5]. Sodium alginate and pectin (2%) can increase the shelf life of fruit [6]. Cassava flour with calcium chloride can maintain the color of French fries [7]. Aloe vera plus carrageenan can increase the lifespan of fruit and vegetable products [8]. The use of polysaccharides as ECF ingredients is not only for vegetables and fruit but also for products such as bread, crackers, and other dry processed products.

Protein-based ECF ingredients include caseins, whey proteins, collagen, gelatin, plasma proteins, myofibrillar proteins, egg white proteins, soy protein, wheat gluten, and zein [9]moisture and oil diffusion, gas permeability (O2, CO2. Using whey protein concentrate mixed with glycerol in various concentrations can prolong the strawberries' life [10]20% and 40% with respect to the solids contained in the mixture WPC/glycerol. Whey protein mixed with glycerol and trehalose inhibited fruits' total phenolics, browning, and weight loss [11]. A whey protein comparison has been made to extend Kilka fish's shelf life [12]. Mixing protein-based ECF ingredients with antioxidants can maintain the quality of fruits and vegetables [13]. Its use extends not only to perishable food products.

Lipid-based ECF ingredients include beeswax, paraffin, polyethylene, jojoba oil, and rice bran wax [13–15]. Lipid-based materials in several layers are used to obtain ideal quality [14]. The mix of ECF and antibacterial substances succeeded in suppressing the growth of mesophilic aerobic bacteria, molds/yeasts, and *Salmonella enterica* in apples [15]. The use of natural waxes (rice bran, carnauba, candelilla, and bees), petroleum-based waxes (paraffin and polyethylene), mineral oils, petroleum-based oils, vegetable oils, acetoglycerides, and fatty acids have been proven effective for ECF ingredients [16]. The use of lipid-based ECF has been widely used in improving the quality and shelf life of food products.

The effectiveness of ECF is influenced by the composition and the ECF application method [3]. In this research, we used the dipping and spray method. Dipping is the most common ECF application method [3,17], which comprises 3 steps: i) immersion & dwelling, ii) precipitation, and iii) solvent evaporation [18]. In the first step, the substrate is immersed in an emulsion/solution layer. The volume of the solution is sufficient to wet the substrate [19]. During evaporation, solvents and excess liquid are evaporated from the surface of the food product using heating and drying procedures [20]. Generally, fruits and vegetables are submerged for 5-30 seconds [21] to extend the shelf life [22].

Spraying is the most common method used in applications for coatings on food products on an industrial scale [20]. There are three types of spraying techniques used in the food industry. The first is air spray atomization. This method uses a high-velocity air spray surrounding the liquid flowing from the tube. Fluid-air friction accelerates, disrupts the fluid flow, and induces atomization [19]. This method includes cost-effective spraying. The presence of an air jet nozzle is to break water (deflector) into fine droplets in spraying. The second is air-assisted airless atomization. In this spray method, the coating sample is atomized and evenly distributed on the substrate surfaces [23]. The third is Pressure atomization. This method does not use air or what is known as airless atomization. Small nozzles with high pressure will provide surface tension and coating viscosity on food products [20].

The spray method is greatly influenced by the size and type of the nozzle. Parameters that affect spraying efficiency include pressure, viscosity, surface temperature, and coating solution stress [24]. In some ECF processes, the spray method may be used for multiple applications, for example, gel layers formed with alginate or calcium chloride solutions [25]. All ECF raw materials play a role in packing food products, and the method used in its application.

Product quality which is the measure in this study, includes a) product age, b) water activity (aw), c) total plate count (TPC), and d) *Escherichia coli* contaminants. These indicators are used to describe the food products quality to find the effectiveness of composite edible coatings and application methods in the ECF process [26, 27].

Based on the description above, the raw materials used can improve the quality and protect food products from being damaged quickly through the dip and spray application methods. No research compares the effectiveness of raw materials against the methods used as practical, efficient, and inexpensive efforts. This study evaluates the effectiveness of several variables from previous researchers and explores the ECF method failures, especially in Indonesia.

MATERIAL AND METHODS

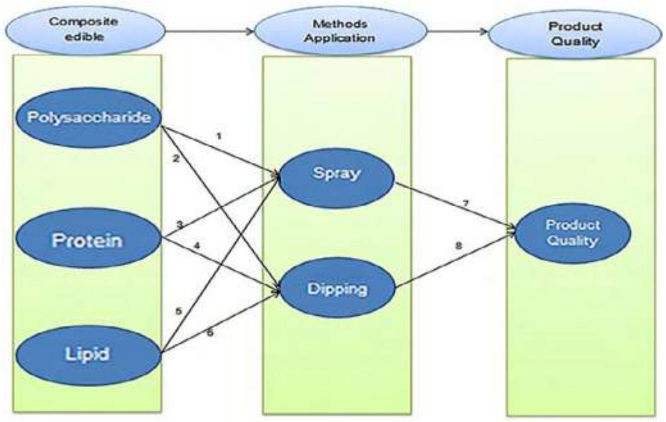
Composite edibles: a) Polysaccharides (starch, cellulose, carrageenan, and pectin); b) Proteins (soy, egg white, casein, gluten, and whey protein; c) Lipids (bee wax, rice bran wax, and paraffin).

Materials for applications: solvents water (polysaccharides) and ethanol (proteins and lipids). Laboratory test materials: Tomato variety of Zamrud (LV 2508), plate count agar (PCA), tryptic soy agar (TSA), buffered peptone water (BPW), distilled water, alcohol 90%.

Equipment: a set of spray tools, a bucket for the dipping process, an autoclave, Petri dishes, an Water Activity meter (Aw) model EZ 200 - Freund, and a microscope MSC-B107.

Research framework

The research framework is shown in Figure 1. There are 14 hypothesis based on the relationship between variables.



9: Polisaccharide ==> Spray ==> Product Quality
10. Polisaccharide ==> Dipping ==> Product Quality
11. Protein ==> Spray ==> Product Quality
12. Protein ==> Dipping ==> Product Quality
13. Lipid ==> Spray ==> Product Quality
14. Lipid ==> Dipping ==> Product Quality

Figure 1. Research framework: Effect of Composite Edible on Product Quality with the Mediation of Application Methods. It has 2 lines of relationship, namely a direct relationship (1,2,3,4,5,6,7,8) and an indirect / mediational relationship (9,10,11,12,13,14). Independent variables (polysaccharide, protein, and lipid) are expected to increase/significantly positive effect on the dependent variable (product quality) through intervening/ mediation variables (spray and dipping).

Research Sample

95 tomato farmers from various regions in Indonesia were involved as respondents in this study. The number and areas of research were: East Java (15), North Sumatra (20), West Java (15), East Nusa Tenggara (20), Jogjakarta (12), and Banten (13). East Nusa Tenggara was the largest contributor of tomatoes in Indonesia, the six regions had uniformity in rainfall (750-1250 mm/year), daytime temperature (18-29°C), relative humidity (25-35%), and soil acidity (pH in the range of 5.5 - 7). This research was assisted by an independent team spread across the area. Our team has obtained permission from the farmers, and the team did not ask for permission from government agencies. Respondents were involved in the application of the ECF method with team assistance. The team analyzed product age, total plate count (TPC), water activity (aw), and *Escherichia coli* contaminants. The study was performed from April 2019 to February 2020.

Work procedures

1. Preparation of ECF referred by Rosida *et al*. [40]: (i) extracts of polysaccharides, proteins, and lipids, as well as solvents/diluents, were weighed to obtain a concentration of 5% (w/v); (ii) Polysaccharide material used water and glycerol as solvent (3:1); (iii) protein ingredients used ethanol (60%), water, and glycerol (2:3:1) as the solvent; (iv) lipids materials used ethanol and glycerol (3:1); (v) heating was employed for materials that were poorly soluble (proteins and lipids); (vi) then cooled and filtered, and finally, the ECF material was ready to be applied.

2. The dipping method (referred by Kowalczewski *et al*. [18]): (i) Tomatoes were put into the reservoir one by one so that the ECF layer covered the entire surface of the tomatoes; (ii) Tomatoes were soaked in ECF solution for 20-30 seconds (MA7) and 30-60 seconds (iii) Tomatoes coated with ECF were removed and placed in an open, well-lit room (without direct sunlight); (iv) The material was drained at room temperature (25-27°C) for 1-2 hours; (v) Ensuring that the ECF layer was dry evenly by physical observation (prick test)

3. The spray method used air-assisted airless atomization, pressure atomization, air spray atomization and air spray-air assisted airless. The process steps, referred by Embuscado [24], were: (i) The ECF solution is made with a viscosity of 0.35–0.60 (10-3 Pa.s); (ii) spray tomatoes with a pressure of 1-2 kPa, additional pressure may be applied if there is a blockage of the spray nozzle; (iii) The thickness of the layer is made between 30-50 µm. Air-assisted airless atomization and pressure atomization can be done in layers because they are easily clogged in the nozzles. (iv) the tomatoes are drained and dried at 25-27°C with enough light (without direct sunlight) for 1-2 hours. Drying time may continue if the prick test shows uneven drying.

Descriptive Statistics

Description analysis was made through SPSS software. The composite edible variable and application methods explore how easy it was to apply ECF. In contrast, the product quality variable based on laboratory analysis results included post-harvest product age, *Escherichia coli*, water activity, and total plate count.

Sorting indicators on each variable using the Principal Component Analysis (PCA) test with SPSS software. The function of PCA in this study is to reduce several variables into new variables or dimensions, which result from indicator extraction [28–30].

Variable Effect Test

The effect of variables was tested using Structural Equation Modeling (SEM) with Partial Least Square (PLS) approach with Smart PLS software version 6.0. The validity test used a cross-loading value > 0.7 [31]W.W., 1998. The partial least squares approach to structural equation modeling. Modern methods for business research, 295(2 and a Square Root of Average Variance Extracted (AVE) value > 0.50 [32]. Reliability test was done with Cronbach's Alpha value > 0.6, Composite Reliability > 0.7 [33]. Structural model testing accommodates all construct variables formulated in hypothesis testing. All standard parameters refer to Hair *et al.* [33].

RESULT

Descriptive Statistics

The following are the results of descriptive analysis of several polysaccharide, protein, lipid, spray, dipping, and product quality variables. This analysis includes indicators of each variable.

Table 1. Analysis of the description of the independent variable and the mediating variable:

Descriptive Statistics Size Scale 1. Very difficult to apply / 2. Difficult to apply / 3, Neutral / 4. Easy to apply / 5. Very easy to apply	N	Minimum	Maximum	Mean		Std. Deviation
Polysaccharide	**Statistic**	**Statistic**	**Statistic**	**Statistic**	**Std. Error**	**Statistic**
Starch (P1)	95	3.00	5.00	3.8500	.10942	.48936
Cellulose (P2)	95	2.00	4.00	3.7000	.12773	.57124
Carrageenan (P3)	95	2.00	4.00	3.4500	.15347	.68633
Pectin (P4)	95	2.00	4.00	3.5500	.13524	.60481
Protein						
Soy Protein (Pr.1)	95	2.00	3.00	2.6000	.11239	.50262
Egg White (Pr.2)	95	2.00	3.00	2.8000	.09177	.41039
Casein (Pr.3)	95	2.00	3.00	2.8500	.08192	.36635
Gluten (Pr.4)	95	3.00	4.00	3.7000	.10513	.47016
Whey Protein (Pr.5)	95	2.00	4.00	3.5500	.13524	.60481
Lipid						
Bee Wax (L1)	95	3.00	4.00	3.5500	.11413	.88704
Rice Bran Wax (L2)	95	3.00	4.00	3.6000	.11239	.47016
Parafin (L3)	95	3.00	4.00	3.6500	.10942	.47016
Spray						
Air assisted airless atomization (MA3)	95	3.00	4.00	3.5500	.11413	.51042
Pressure atomization (MA4)	95	3.00	4.00	3.6000	.11239	.50262
Air spray atomization (MA5)	95	3.00	4.00	3.6500	.10942	.48936
Air spray-Air assisted airless (MA6)	95	3.00	4.00	3.5500	.11413	.51042
Dipping						
Duration (20-30) sec. (MA7)	95	3.00	5.00	3.9500	.13524	.60481
Duration (30-60) sec. (MA8)	95	3.00	5.00	3.7500	.12301	.55012

Table 1: Application process of a method (spray and dipping) using ECF raw materials (polysaccharide, protein, and lipid). The data explored the ease of application of ECF. Based on the average, the order of variables that have the greatest value was dipping, polysaccharide, spray, lipid, and protein. The indicators for each variable are as follows: Dipping (MA7); polysaccharide (P1); spray (MA5); lipids (L3), and proteins (Pr.4). The indicators above are still being screened again through PCA and SEM PLS analysis.

Table 2. Analysis of the description of the dependent variable

Descriptive Statistics

Size Scale

Damage Duration (day)	:	1 (5-10)	2. (10-14)	3. (14-18)	4. (18-22)	5. (22-24)
Escherichia coli (MPN/ml)	:	1. (80-100)	2. (60 - 80)	3. (40-60)	4. (20-40)	5. (10 – 20)
Total Plate Count (10^5 CFU/ml)	:	1. (80-100)	2. (60-80)	3. (40-60)	4. (20-40)	5. (0-20)
A_w	:	1. (0.95-0.1)	2. (0.90-0.95)	3. (0.85-0.90)	4.(0.80-0.85)	5. (0.7-0.8)

	N	Minimum	Maximum	Mean		Std. Deviation
	Statistic	**Statistic**	**Statistic**	**Statistic**	**Std. Error**	**Statistic**
Damage Duration (PQ1)	95	3.00	4.00	3.7500	.09934	.48936
Escherichia coli (PQ2)	95	3.00	4.00	3.8000	.09177	.57124
Total Plate Count (PQ3)	95	2.00	4.00	3.6000	.15218	.68633
Water Activity (PQ4)	95	2.00	4.00	3.5000	.17014	.60481

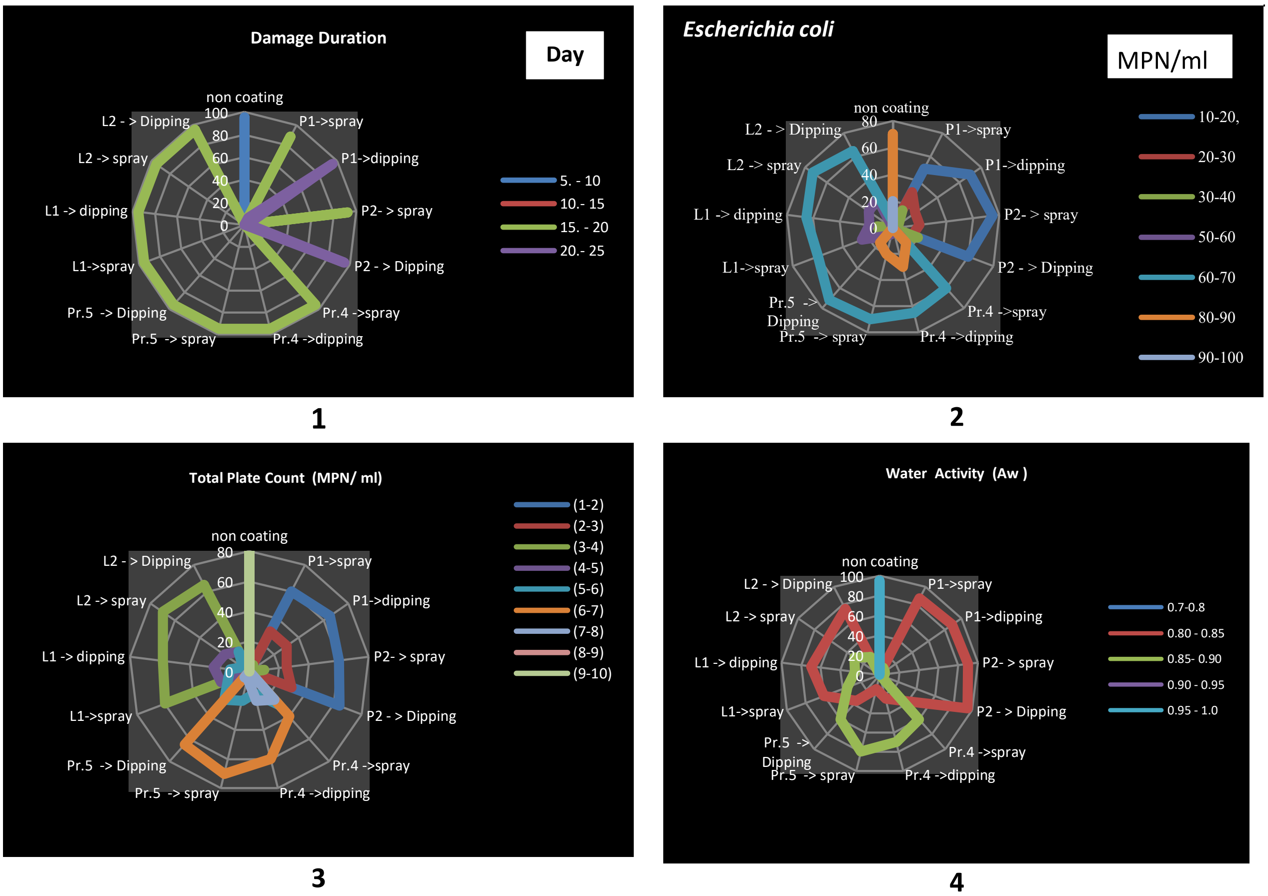


Figure 2. Result of indicator analysis of product quality variable.

Polysaccharide coating material: starch (P1), cellulose (P2), carrageenan (P3), and Pectin (P4). **Protein** coating material: soy protein (Pr.1), egg white (Pr.2), casein (Pr.3), gluten (Pr.4), and whey protein (Pr.5). **Lipid** coating material: bee wax (L1), rice bran wax (L2), and parafin (L3). The coating process used the **spray** method: air assisted airless atomization (MA3), pressure atomization (MA4), air spray atomization (MA5), and air spray-air assisted airless (MA6). Dipping method: duration (20-30) sec. (MA7) and duration (30-60) sec. (MA8).

Damage duration (1): tomatoes were damaged between 5-10 days (non-coating); the dipping method avoided the damage between 20-25 days (starch (P1), cellulose (P2)), while the polysaccharide applied by spraying can avoid the damage up to 15-20 days. The dipping and spray methods extended the life span to 15-20 days for protein and lipid materials. ***Escherichia coli*** (2): Noncoating has a contaminant range of 80-100 MPN/ml. The dipping method for polysaccharides has a contaminant range of 10-30 MPN/ml, the spray method (10-40 MPN/ml). Protein and lipid materials by spray and dipping methods ranged from 60-80 MPN/ml. **Total Plate Count** (3): non coating (8-10 x 105 CFU/ml), polysaccharide dipping and spray method (1-3 x 105 CFU/ml), protein (5-7 x 105 CFU/ml), and lipid (3-5 x 105 CFU/ml). **Water activity** (4): non-coating (0.95-1.0). Dipping and spray methods for polysaccharides (0.80-0.85), proteins, and lipids had the same Aw (0.85-0.90).

Table 3. Determination of variable indicators with Principal Component Analysis

Indicator	Code	Rotation Method: Varimax with Kaiser Normalization VARIABLE (* significant p=0.05)					
		Polysaccharide	Protein	Lipid	Spray	Dipping	Product Quality
Starch (P1)	P1	.658*	.432	.346	.497	.276	.345
Cellulose (P2)	P2	.745*	.375	.368	.248	.366	.335
Carrageenan (P3)	P3	.749*	.398	.475	.399	.375	.445
Pectin (P4)	P4	.763*	.365	.472	.332	.487	.467
Soy Protein (Pr.1)	Pr.1	.347	.793*	.389	.337	.309	.375
Egg White (Pr.2)	Pr.2	.452	.668*	.396	.371	.364	.385
Casein (Pr.3)	Pr.3	.257	.676*	.385	.351	.354	.374
Gluten (Pr.4)	Pr.4	.367	.756	.298	.383	.378	.348
Whey Protein (Pr.5)	Pr.5	.392	.665*	.389	.374	.441	.347

Indicator	Code	Rotation Method: Varimax with Kaiser Normalization VARIABLE (* significant p=0.05)					
		Polysaccharide	Protein	Lipid	Spray	Dipping	Product Quality
Bee Wax (L1)	L1	.298	.349	.749*	.382	.342	.345
Rice Brand Wax (L2)	L2	.438	.483	.783*	.364	.341	.355
Paraffin (L3)	L3	.472	.342	.658*	.298	.362	.385
Air assisted airless atomization (MA3)	MA3	.435	.352	.367	.745*	.324	.395
Pressure atomization (MA4)	MA4	.389	.267	.476	.749*	.268	.375
Air spray atomization (MA5)	MA5	.482	.367	.487	.763*	.337	.345
Air spray-Air assisted airless (MA6)	MA6	.473	.392	.387	.684*	.452	.358
Duration (20-30) sec. (MA7)	MA7	.378	.372	.443	.365	.783*	.348
Duration (30-60) sec. (MA8)	MA8	.238	.435	.344	.428	.682*	.345
Damage Duration (PQ1)	PQ1	.349	.389	.364	.378	.391	.794*
Escherichia coli (PQ2)	PQ2	.487	.482	.361	.456	.386	.765*
Total Plate Count (PQ3)	PQ3	.298	.473	.358	.386	,364	.773*
Water Activity (PQ4)	PQ4	.389	.481	.374	.354	.347	.765*

Determination of variable indicators using loading > 0.6 and p = 0.05. The blue color shows the indicator of the variable. Polysaccharides (P1,P2,P3,P4); Proteins (Pr1,Pr2,Pr3,Pr4,Pr5); Lipids (L1,L2,L3); Spray (MA3,MA4,MA5,MA6); Dipping (MA7,MA8); Product quality (PQ1,PQ2,PQ3,PQ4). Determination of variable indicators using the PCA method is used to test the effect of the relationship between variables.

Variable Effect Analysis

The effect of variables was tested using Structural Equation Modeling (SEM) with Partial Least Square (PLS) approach with Smart PLS software. The variable indicators in table 3 will be re-evaluated based on the loading factor > 0.7 so that some indicators were omitted because the value is < 0.7.

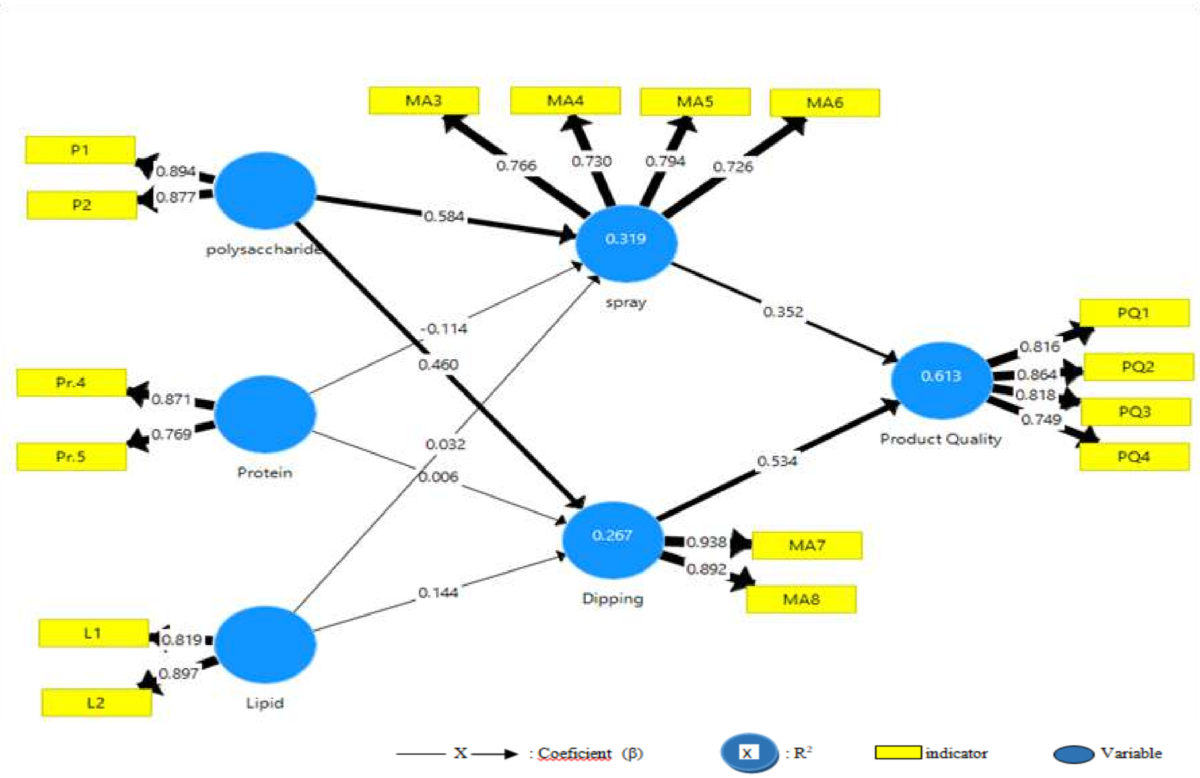


Figure 3. Analyzes of the relationship between variables using the SEM PLS method to test the model's validity and reliability before testing between variables. If the validity and reliability tests have not been met, then the variable influence test cannot be carried out in this analysis.

Table 4. Test the Validity and Reliability of the Model

Test	Parameter	Standard	Results
Convergent Validity	Factor loading (outer loading)	>0.6	0.726-0.938
	AVE (Average Variance Extracted)	>0.5	0.581– 0.684
	Communality	>0.5	0.581 – 0.684
Discriminant Validity	Root Square AVE and Corelation variabel latent	Root Square AVE > Discriminant validity	Root Square AVE> Discriminant Validity
	Cross Loading	>0.6	0.726 – 0.906
Reliability	Cronbach's Alpha	>0.6	0.614 – 0.827
	Composite Reliability	>0.7	0.807 – 0.878

Referring to table 4, all parameters are included in the standard validity and reliability test of the instrument so that it can be used for analysis of variable relationships in a model.

Table 5. Test the effect between variables

hypothesis	Paths	Coeficient (β)	T statistics >1.65	p Value < 0.05	f^2	Remark
1	Polysaccharide => Spray	0.584	2.727	0.007	0.141	(+) significant
2	Polysaccharide => Dipping	0.460	2.290	0.022	0.097	(+) significant
3	Protein => Spray	-0.114	0.411	0.681	0.004	(-) not significant
4	Protein =>Dipping	0.006	0.405	0.686	0.005	(+) not significant
5	Lipid => Spray	0.032	0.078	0.937	0.000	(+) not significant
6	Lipid =>Dipping	0.144	0.862	0.389	0.017	(+) not significant
7	Spray => Product Quality	0.352	3.267	0.001	0.253	(+) significant
8	Dipping => Product Quality	0.534	5.489	0.000	0.489	(+) significant
9	Polysaccharide => Spray => Product Quality	0.135	2.189	0.029		(+) significant
10	Protein => Spray => Product Quality	0.025	0.385	0.701		(+) not significant
11	Lipid => Spray => Product Quality	-0.007	0.077	0.938		(-) not significant
12	Polysaccharide => Dipping => Product Quality	0.155	2.143	0.033		(+) significant
13	Protein => Dipping => Product Quality	0.038	0.403	0.687		(+) not significant
14	Lipid => Dipping => Product Quality	0.071	0.858	0.391		(+) not significant

f^2 : 0.02- 0.15 Weak Effect; f^2 : 0.15-0.35 Sufficient Effect ; f^2 : ≥ 0.35 Strong Effect
R^2: Spray 0.319; Dipping 0.267; Product quality 0.613

The effect of the (+) significant variable indicates that the ECF raw material is easy to apply with the dipping and spray methods to maintain the quality of the tomatoes. Polysaccharides can prove this condition as raw material for ECF. The significant (-) effect describes the less than optimal application so that it has not given maximum results to the quality of tomatoes. This is indicated by the fact that obstacles in applying for proteins, and lipids are still found. The dipping method gave the greatest protective effect on tomatoes (48.9%) compared to the spray method (25.3%) using polysaccharides.

DISCUSSION

This study aims to compare the effect of composite edible on product quality with the mediation of application methods. Referring to the composite edible, the raw material with the biggest effect is polysaccharide, and the weakest effect is protein. The effect test is seen from the direct effect (composite edible on application methods) and indirect effect (composite edible on product quality with the mediation of application methods). Based on the relationship between variables, the most significant effect is shown by the relationship between the dipping variable on product quality, and the lowest effect is lipid on spray.

Polysaccharide has the greatest influence on both direct relationship (Polysaccharide →Spray) and indirect relationship/mediation (Polysaccharide → Dipping → Product Quality). Polysaccharides are easily soluble in water, so farmers in Indonesia widely use them. Polysaccharides are abundant and relatively inexpensive raw materials. This raw material tends to be stable in the spray and dipping method. However, in the spray method, there are cases of nozzle blockage. This condition is not as severe as proteins and lipids materials. Those tend to be hygroscopic, favoring the growth of contaminant microorganisms; besides, the selection of raw materials must pay attention to tensile strength (not easily broken on pull) and puncture strength. Types of starch and cellulose were included in the selection of raw materials. No cracks occurred in layers with a thickness of 30μm (dipping = 20-30 seconds) and 40μm (dipping = 30-40 seconds). This finding strengthens the results of previous studies [6,34].

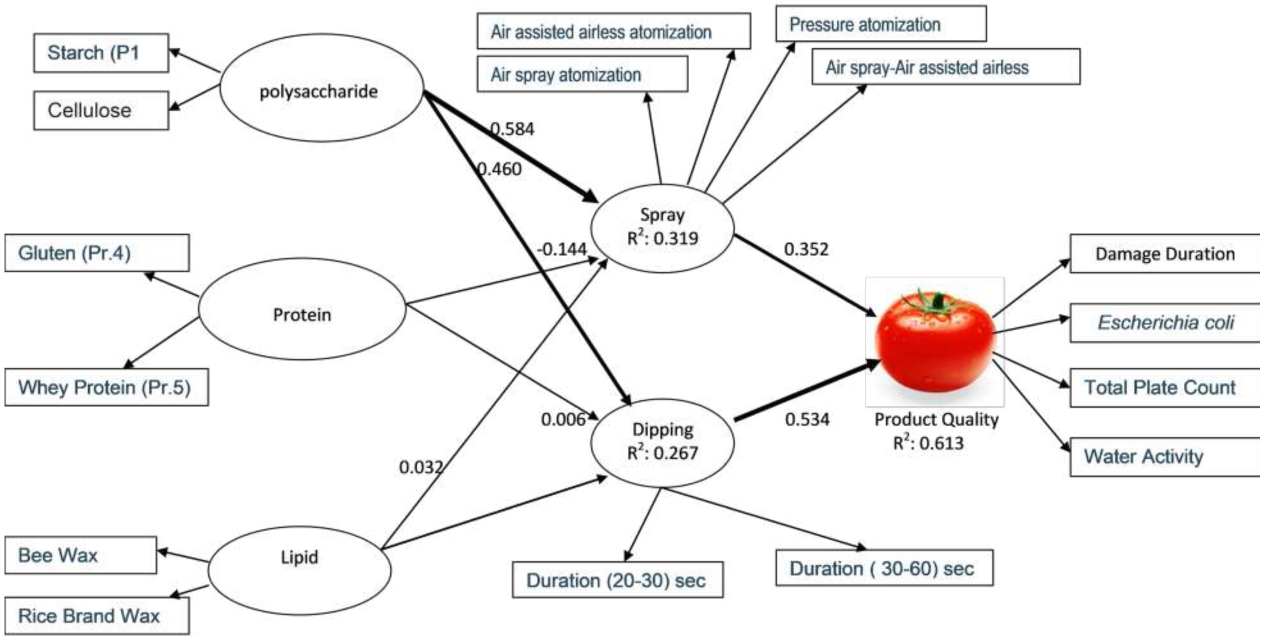


Figure 4. Composite Edible Relationship Model on Product Quality with the Mediation of Application Methods. The spray variable reflected 31.9% of the polysaccharide, protein, and lipid variables. The Dipping variable reflected 26.7% of the polysaccharide, protein, and lipid variables. Product quality was reflected by the variable spray and dipping of 61.3%.

Protein has the slightest effect on direct (Protein → spray) and indirect (Protein → Spray → Product quality) relationships. Protein did not affect the spray method. The field observations showed frequent blockages in the spray nozzles for several types of protein, although the viscosity was the same as that of polysaccharides and lipids. The findings of this constraint support the research conducted by [35]. Physical properties, including tensile and puncture strength, were shallow compared to polysaccharide and lipid materials. This has been experienced by [36], causing less than maximum protection against water vapor. Gluten contains gliadins and glutenins. Gliadin is soluble in 70% ethanol, but glutenin is insoluble. This condition is supported by the findings of Dhaka & Upadhyay [37]. Although gluten has good solubility in low and high pH, it is not soluble in water.

Lipids had no significant positive effect on the spray and dipping methods. The observations in the field showed that the gloss of tomato coated with lipids spoiled the appearance. This finding was supported by previous researchers [36, 37]. Rotten due to the oxidation process is an obstacle for lipid-based raw materials, so the thickness of the layer needs to be increased (>30 μm). Additionally, increased ECF thickness will affect the sensory properties of tomatoes. The lipid layer is very effective in keeping the tomato fruit moist because of its low polarity. The rice bran wax coating layer was cracked by dipping and spraying methods. A multi-layer layer will give an uneven surface to tomatoes.

The spray method has a 25.3% effect on product quality. Only polysaccharides had a significant positive effect (58.3%; $p<0.05$) on the spray method. Therefore, there are no obstacles to applying polysaccharides in the spray method. Proteins and lipids did not affect the spray application. The obstacles found in the field were: a) there was a blockage in the nozzle (material from lipids and proteins) so it had to be diluted to a viscosity of 0.35-0.60 x10^{-3} Pa.s. This finding supports the results of Berkland *et al*. [38]. b) The use of high pressure ranges from 10-50 kPa, while the polysaccharide only ranges from 1-2 kPa. c) A special nozzle is required for these materials, and post-use care is required. d) Spraying efficiency includes pressure, viscosity, surface temperature and tension of the coating solution, along with the shape and design of the spray nozzle.

The dipping method has a 48.9% effect on product quality. Polysaccharides can significantly affect dipping applications. There were no cracks in the coating layer on immersion for 20-30 seconds (30μm) and 30-60 seconds (40μm). The opposite condition occurred in protein and lipid materials. Prolonged immersion will provide a thick layer that interferes with the respiration process of tomatoes, this finding strengthens the research of Khare *et al*. [39], and Menezes & Athmaselvi [6]. Disadvantages of the dipping method are the accumulation of dirt and the development of microbes in the container.

The ineffectiveness of proteins and lipids is due to many obstacles in the spray process; the farmers are not familiar with spray and prefer the dipping method because it is more practical and easier to apply. Only 23% of the 95 respondents used the spray method. This study illustrates that many investigations related to ECF with the spray method have not been able to be applied optimally.

Referring to the discussion above, an effective, efficient and inexpensive raw material for ECF is a polysaccharide that has strong characteristics on tensile and puncture tests. The method that can be used is the dipping method which always pays attention to: 1) the contamination factor of microorganisms and sanitation due to the accumulation of solvents. 2) pay attention to the immersion time on the thickness of the ECF layer. The thickness of the ECF will interfere with the respiration process of tomatoes. The spray method can be used by always paying attention to: 1) uniform spray thickness on each side of the surface; 2) nozzle clogging is anticipated by adjusting the viscosity of the ECF 5% solution (0.35–0.60 x10-3 Pa.s) and At low pressure (>10kPa), the protein concentration was more effective at 3% (w/v) while the lipid was 3-4% (w/v); 3) Multi-layer applications pay more attention to the first layer to avoid cracks. This will affect the cracks in the next layer.

The limitation of this study relates to farmer respondents who are not familiar with the technology (spray method) so that the method is not optimal in its application. The raw materials used are polysaccharides, which have abundant resources, so that the use of protein and lipid-based raw materials has received less attention.

CONCLUSION

The three edible coating film materials can improve the quality of tomatoes and extend the shelf life of tomatoes. Polysaccharides have the greatest effectiveness compared to proteins and lipids with the dipping and spray application methods. This cannot be separated from the habit of using polysaccharides as raw material for edible coating films due to their abundant availability.

The dipping method is better than the spray method based on the effect test (f2), coefficient (β) with ***p*** value <0.05 even though the dipping variable can only be understood/understood by polysaccharides, proteins, and lipids by 26.7% (R2) while the spray is 31.9%. The biggest obstacles in the application that are often found with the spray method are in the form of a spray flow that is not smooth (clogged nozzle), viscosity, pressure, cracks after the drying process. The use of the spray method is more complicated than the dipping method, so technical matters must be considered to obtain optimal results.

The ineffectiveness of proteins and lipids in the spray method with a concentration of 5% (w/v) can be anticipated with a dilution of 0.35–0.60 (10-3 Pa.s), a spray pressure of 10-50 kPa, and a special anti-clogging nozzle. At low pressure (>10kPa), the protein concentration was more effective at 3% (w/v) while the lipid was 3-4% (w/v). In the dipping method, cracking can be anticipated with a shorter immersion time (maximum 20 seconds) compared to immersion in polysaccharides (20-40 second).

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