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Universidade Estadual de Maringá
Centro de Ciências Agrárias
Programa de Pós-Graduação em Ciência de Alimentos

PARANÁ
GOVERNO DO ESTADO

ATA DA BANCA EXAMINADORA DA DEFESA DE DISSERTAÇÃO DE MESTRADO DA PÓS-GRADUANDA JÉSSICA DE SOUZA ALVES FRIEDRICHSEN. Aos vinte e sete dias do mês de outubro de dois mil e vinte e dois às quatorze horas, reuniu-se por webconferência, em conformidade com a Portaria CAPES nº 36, de 19 de março de 2020, Portaria nº 122/2020-GRE/UEM e Ato Executivo nº 004-2020-GRE/UEM a Banca Examinadora de dissertação em epígrafe, composta pelos Professores Doutores: Oscar de Oliveira Santos Júnior, Paulo Ricardo de Souza, Alessandro Francisco Martins, sob a presidência do primeiro. A sessão foi aberta pelo professor presidente que apresentou os membros da banca examinadora, passando em seguida a palavra a candidata para que fizesse uma exposição de seu trabalho, intitulado: "Edible coatings based on cassava starch incorporating soybean oil: potential application for prolonging the shelf life of strawberries (Fragaria ananassa) cv San Andreas". Terminada a exposição, houve um pequeno intervalo, sendo posteriormente a candidata arguida pelos membros da Banca Examinadora. Após as arguições, a Banca Examinadora procedeu ao julgamento, sendo, ao final, a pós-graduanda **JÉSSICA DE SOUZA ALVES FRIEDRICHSEN**, candidata ao Título de **Mestre em Ciência de Alimentos,** considerada **APROVADA**. Este resultado deverá ser homologado pelo Conselho do Programa de Pós-graduação em Ciência de Alimentos da Universidade Estadual de Maringá. Nada mais havendo a tratar, o Senhor Presidente encerrou os trabalhos. Para constar, foi lavrada a presente Ata, que vai assinada pelos membros da Banca Examinadora, após lida e achada conforme. Maringá, vinte e sete dias do mês de outubro de dois mil e vinte e dois.

Prof. Dr. Oscar de Oliveira Santos Júnior — Oscar de O S Jr
Presidente

Prof. Dr. Paulo Ricardo de Souza — Paulo Ricardo de Souza
Membro

Prof. Dr. Alessandro Francisco Martins — Alessandro F. Martins
Membro

JÉSSICA DE SOUZA ALVES FRIEDRICHSEN

"EDIBLE COATINGS BASED ON CASSAVA STARCH INCORPORATING SOYBEAN OIL: POTENTIAL APPLICATION FOR PROLONGING THE SHELF LIFE OF STRAWBERRIES (FRAGARIA ANANASSA) CV SAN ANDREAS".

Dissertação apresentada à Universidade Estadual de Maringá, como parte das exigências do Programa de Pós-graduação em Ciência de Alimentos, para obtenção do grau de Mestre em Ciência de Alimentos.

Paulo Ricardo de Souza
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Orientador

Maringá – 2022

UNIVERSIDADE ESTADUAL DE MARINGÁ
CENTRO DE CIÊNCIAS AGRÁRIAS
Programa de Pós-Graduação em Ciência de Alimentos

EDIBLE COATINGS BASED ON CASSAVA STARCH INCORPORATING SOYBEAN OIL: POTENTIAL APPLICATION FOR PROLONGING THE SHELF LIFE OF STRAWBERRIES (*FRAGARIA ANANASSA*) CV SAN ANDREAS

JÉSSICA DE SOUZA ALVES FRIEDRICHSEN

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JÉSSICA DE SOUZA ALVES FRIEDRICHSEN

Edible coatings based on cassava starch incorporating soybean oil: potential application for prolonging the shelf life of strawberries (*Fragaria ananassa*) cv San Andreas

Dissertação apresentada ao programa de Pós Graduação em Ciência de Alimentos da Universidade Estadual de Maringá, como parte dos requisitos para obtenção do título de mestre em Ciência de Alimentos

Maringá

2022

Orientador

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BIOGRAFIA

Jéssica de Souza Alves Friedrichsen, nasceu em Marialva-PR. Na cidade de Umuarama Possui graduação em Química Industrial - Bacharelado pela Universidade Paranaense – UNIPAR. Tem experiência na área de Ciência de Alimentos atuando principalmente nos seguintes temas: Tecnologia de alimentos, composição de alimentos, desenvolvimento de novos produtos alimentícios.

Dedico

A minha família em especial a minha mãe Maria Pereira de Souza Alves, a Ilma Pereira de Souza Zamboni e ao meu esposo Jonathan Friedrichsen, por todo apoio concedido as minhas escolhas e sonhos. E com muito carinho a minha amiga Eloize Silva Alves, que me apoiou em todo o momento, ainda aos meus colegas de pesquisa por todos os ensinamentos.

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APRESENTAÇÃO

Esta dissertação de mestrado está apresentada na forma de um artigo científico.

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Título: Edible coatings based on cassava starch incorporating soybean oil: potential application for prolonging the shelf life of strawberries (*Fragaria ananassa*) cv San Andreas.

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GENERAL ABSTRACT

INTRODUCTION. Strawberry is a non-climacteric pseudofruit, of considerable commercial and nutritional importance that adapts to various environmental conditions of cultivation worldwide, and its world production in 2019 reached almost 8.9 million tons (Yang et al., 2022). However, strawberries are highly perishable and susceptible to mechanical damage, physiological deterioration, water loss, and decomposition, thus altering their sensory characteristics and physicochemical composition. For this reason, strawberry losses are high from harvest to distribution, generally having a postharvest shelf life of 3-5 days at room temperature (Muley & Shingal, 2020). The significant value loss of fruit waste is mainly due to high perishability. As an alternative to minimize the high perishability and increase the shelf life of fruits, a lot of research has been emerging in the scope of the use of biodegradable films and coatings edible to reduce the problems faced in production and commercialization (Gómez-Contreras et al., 2021). Therefore, applying films and coatings edible becomes a promising alternative, acting in the conservation of strawberries. Polysaccharides, proteins, and lipids are used as developing systems for films and edible coatings. The incorporation of lipids in edible coatings has been carried out by the emulsion process, with the addition of monoglycerides, diglycerides, triglycerides, and lecithin, able to stabilize dispersed systems (Gutiérrez-Jara et al., 2020). Different materials, such as cassava starch, soybean oil, soy lecithin, glycerin, and PVOH, were used for the elaboration of films and coatings edible for application in fresh strawberries in the conservation of quality.

AIMS. In this context, the present study aims to develop and characterize edible films by the casting method, in addition to evaluating your application as a coating on fresh strawberries minimizing their perishability, and evaluating their physiological deterioration, increasing their shelf life under environmental conditions of storage 25±5 ºC.

MATERIAL AND METHODS. An emulsion was formed between soybean oil, distilled water, and soy lecithin, under magnetic stirring, separately and after being added. The starch, previously dissolved in distilled water, was added in sequence under continuous stirring. After the mixture was homogeneous, heated to 90 ± 2 °C for starch gelatinization. Subsequently, the solution was transferred to an ultrasonic bath (ELMA, Elmasonic P, São Paulo, Brazil) at an 80 kHz frequency for 10 min to remove air bubbles caused by the stirring process. For application on strawberries, 80 fruits were selected according to the absence of physiological factors, free of visible stains, with uniformity of size and apparent color. Subsequently, 20 strawberries were used as controls without the coating, while the others (60) were immersed in the solutions filmogenic for about 20 s and dried for 24 h at 25.05±1.05 °C. The moisture contents (MC) were determined gravimetrically, according to Versino & Garcia (2014). The solubility in water (SW) of the films was determined according to the methodology described by Ma et al. (2017). The swelling degree (SD) was measured gravimetrically according to Riyajan, & Chantawee (2020). Water vapor permeability (WVP) was determined gravimetrically according to Garcia et al. (2014). Color analysis was performed using a Minolta Chroma Meter CR-400 digital colorimeter (Konica Minolta, Osaka, Japan), the total color difference (ΔE) was calculated. The capacity of the barrier to UV radiation was evaluated by following the methodology of Versino & Garcia (2014), with modifications. The apparent opacity (Po) of the sample was

measured as described by Abdillah & Charles (2021). The thickness was determined using a digital external micrometer. The mechanical properties of the films were measured using a texture meter. Assays were performed according to Garcia et al. (2014). Tensile strength (σ - MPa), elongation at break (ε - %), and Young's modulus (MPa) of specimens (2.5 x 5 cm) were evaluated. FTIR spectra were obtained on a Thermo Fisher Scientific infrared spectroscope. The samples' surface morphology was evaluated by Scanning electron microscope (SEM) (Fisher Scientific-FEI, Czech Republic). The weight loss was evaluated according to Muley and Shangay (2020), with some modifications. Characterization of coated fresh strawberries, the total soluble solids (TSS) content was determined by evaluating the pulp of the selected fruits using a digital refractometer (Hanna Instruments, model HI96801). The analyzes were performed in triplicate, and the results expressed in °Brix. The pH measurement was adapted from Muley & Shangay (2020). The color determination was determined from the pulp of the control and coated fruits.The results were submitted to analysis of variance (ANOVA) and Tukey's test to compare means ($p < 0.05$) using the Statistic 7.0 software (StatSoft Inc., Tulsa, USA).

RESULTS AND DISCUSSION. The addition of soybean oil to the solutions filmogenic (2.5, 3.0, and 3.5) reduced the value of MC in the films when compared to those that did not contain oil (2.5C, 3.0C, and 3.5C). However, this reduction was not enough to significantly differ between them ($p > 0.05$), where this percentage ranged from 9.26±0.95 (3.0) to 11.43±2.25 (2.5C). The SW percentage results of the films ranged from 27.55±5.37 (3.5) to 43.09±7.06 (3.5C), results that differed significantly ($p > 0.05$). This difference occurs because formulation 3.5 has soybean oil. The 3.5C formulation has no oil, thus having more hydroxyls available to interact with water molecules. The other formulations did not differ significantly. The percentage values of SD, for the films ranged from 1346.58±78.73 to 2732.83±869.79, with no significant differences ($p > 0.05$). The WVP evaluation is an important parameter to guarantee the organoleptic properties of stored vegetables and fruits. Of the evaluated films, those without the addition of soybean oil (2.5 C, 3.0 C, and 3.5 C) showed significant differences ($p > 0.05$) from those with the addition of oil (2.5, 3.0, and 3.5), the latter with lower WVP values. According to Table 2, the films that presented a higher barrier to UV light were 3.0 and 3.5. On the other hand, the films 2.5, 3.0C, and 3.5C did not present a difference significantly ($p > 0.05$). The Po can vary according to the film forming agents, where increasing the concentration of cassava, oil, and starch can increase the films' opacity. Demonstrate that film 2.5 presented the highest value and 3.5C had the lowest opacity value, while 3.0, 2.5C, and 3.0C showed similarity ($p < 0.05$). These results demonstrate the applicability of the 2.5 films, as they achieved desirable transparency compared to other formulations. This trend value can be correlated with adding soy oil and lecithin to formulations, higher for formulation 3.5. The yellowish color of these components is due to the presence of vitamin E and carotenoids in their composition. The correlation is seen for the values of ΔE *, higher when the concentration of oil and soy lecithin in the filmogenic formulation is raised. The thickness variation was (0.067 to 0.157 mm) varying significantly ($p < 0.05$). The 3.5C film exhibited the greatest thickness. On the other hand, the smallest was recorded by the 2.5 films. Mechanical properties are of great importance for many applications, including food packaging. As observed in films containing soybean oil, where the maximum elongation of the 3.0 film was 2.766. FTIR spectra of the films obtained are shown therefore, we can infer an interaction between the lecithin and starch molecules with the other components. This fact can be attributed to the interaction of soybean oil with lecithin (hydrophobic portion) since the soybean oil/lecithin ratio is the same for the samples. The surface characteristics of the composite films were evaluated by SEM, as shown additionally, it is observed that most samples have cracks in different proportions, as observed in all images, except for the image referring to the 3.0 film. As observed, the 3.0 and 3.0C films have a lower rate of cracks. Of the evaluated solutions filmogenic initially represented in Table S1, only those with the addition of soybean oil (2.5, 3.0, and 3.5) were applied as an edible coating on fresh strawberries. This is due to the results obtained in the characterization analysis and mainly the influence of hydrophobicity by the addition of soybean oil. Therefore, these three formulations and without coating (control strawberry - CS) were applied to fresh strawberries. Strawberries were stored and evaluated at room temperature (25±5 °C) for 10 days. Visually, the difference between the CS and solutions 2.5, 3.0, and 3.5 demonstrate the influence of coatings on fruit senescence during storage at 25±5 ºC. The films with the highest concentration of oil and starch, respectively 3.0, and 3.5, showed significant physiological deterioration with fungal growth, is due to the greater thickness of these films due to the higher concentration of starch and soybean oil. Coating 2.5 stimulated better conservation of the strawberry until the end of the evaluation, is due to the lower thickness and amount of soybean oil, guaranteeing the conservation and gas exchange of the strawberry. In evaluating strawberry weight loss, a gradual reduction was observed during storage of the CS, 3.0 and 3.5, demonstrating that they do not meet the characteristics of strawberry preservation. Coating 2.5 had a better response than other formulations throughout the storage period. The evaluation of TSS is related to the fruit's formulation 2.5 differed significantly from the others since it maintained values below 11 °Brix and slight variation during the 10 days of evaluation. Strawberry pH can vary depending on other conditions such as climate, management, and variety, since the same cultivar may have different pH values. The pH value of the CS and coated strawberries during storage at 25±5 ºC for 10 days is shown in Fig. 3c. We can see that on day 1, the pH ranged from 3.26 to 3.36, with no significant difference in values , and demonstrated that the filmogenic solutions used do not significantly alter the pH values when applied to strawberries. In all parameters, the variation in the color of the pulp of the coated strawberries did not show significant differences concerning CS due to the coating having optical properties of transparency, being pronounced the natural color of the strawberries, as the solution adhered evenly to its surface. Other factors that may contribute to the increase in redness of strawberries were the concentration of their TSS concentration, and the stability of their pigments (anthocyanins) caused by the weight loss (water). Sample CS was the most impacted in relation to these factors, in addition to the deterioration process being more advanced.

CONCLUSION. The formulations with the addition of soybean oil demonstrated efficiency in the face of the characteristics evaluated in the films by this casting method. Soybean oil emulsifies in the film network, decreasing the availability of free hydroxyls in hydrogen bonds. It was possible to obtain a longer shelf life, from 3 days (SC) to 10 days (2.5) under storage at 25±5 ºC. The application of formulation 2.5 reached the maintenance of quality, caused a slowdown in metabolism and physiological deterioration of the strawberries, indicating to be a promising alternative to reduce their perishability, and reduce economic losses. Overall, the application of coatings proved to be innovative to prolong the shelf life of strawberries to 10 days, reducing their perishability, and physiological deterioration, and keeping their physical properties unchanged.

Keywords: Composite films. Lipids. Soybean oil. Strawberry conservation.

RESUMO GERAL

INTRODUÇÃO. O morango é um pseudofruto não climatérico, de considerável importância comercial e nutricional que se adapta a diversas condições ambientais de cultivo em todo o mundo, e sua produção mundial em 2019 atingiu quase 8,9 milhões de toneladas (Yang et al., 2022). No entanto, os morangos são altamente perecíveis e suscetíveis a danos mecânicos, deterioração fisiológica, perda de água e decomposição, alterando suas características sensoriais e composição físico-química. Por esta razão, as perdas de morango são altas desde a colheita até a distribuição, geralmente tendo uma vida útil pós-colheita de 3-5 dias à temperatura ambiente (Muley & Shingal, 2020). A perda significativa de valor dos resíduos de frutas se deve principalmente à alta perecibilidade. Como alternativa para minimizar a alta perecibilidade e aumentar a vida útil das frutas, muitas pesquisas vêm surgindo no âmbito da utilização de filmes biodegradáveis e revestimentos comestíveis para reduzir os problemas enfrentados na produção e comercialização (Gómez-Contreras et al., 2021). Portanto, a aplicação de filmes e coberturas comestíveis torna-se uma alternativa promissora, atuando na conservação de morangos. Polissacarídeos, proteínas e lipídios são usados como sistemas de desenvolvimento para filmes e revestimentos comestíveis. A incorporação de lipídios em revestimentos comestíveis tem sido realizada pelo processo de emulsão, com adição de monoglicerídeos, diglicerídeos, triglicerídeos e lecitina, capazes de estabilizar sistemas dispersos (Gutiérrez-Jara et al., 2020). Diferentes materiais, como fécula de mandioca, óleo de soja, lecitina de soja, glicerina e PVOH, foram utilizados para a elaboração de filmes e coberturas comestíveis para aplicação em morangos frescos na conservação da qualidade.

OBJETIVO. Nesse contexto, o presente estudo tem como objetivo desenvolver e caracterizar filmes comestíveis pelo método casting, além de avaliar sua aplicação como revestimento em morangos frescos minimizando sua perecibilidade, e avaliar sua deterioração fisiológica, aumentando sua vida útil em condições ambientais de armazenamento. 25±5ºC.

MATERIAL E MÉTODOS. Formou-se uma emulsão entre óleo de soja, água destilada e lecitina de soja, sob agitação magnética, separadamente e após adição. O amido, previamente dissolvido em água destilada, foi adicionado sequencialmente sob agitação contínua. Após a mistura ficar homogênea, aqueceu-se a 90 ± 2°C para gelatinização do amido. Posteriormente, a solução foi transferida para um banho ultrassônico (ELMA, Elmasonic P, São Paulo, Brasil) na frequência de 80 kHz por 10 min para remover as bolhas de ar causadas pelo processo de agitação. Para aplicação em morangos, foram selecionados 80 frutos de acordo com a ausência de fatores fisiológicos, isentos de manchas visíveis, com uniformidade de tamanho e cor aparente. Posteriormente, 20 morangos foram utilizados como controle sem o revestimento, enquanto os demais (60) foram imersos nas soluções filmogênicas por cerca de 20 s e secos por 24 h a 25,05±1,05 °C. Os teores de umidade (CM) foram determinados gravimetricamente, conforme Versino & Garcia (2014). A solubilidade em água (SW) dos filmes foi determinada de acordo com a metodologia descrita por Ma et al. (2017). O grau de inchaço (SD) foi medido gravimetricamente de acordo com Riyajan, & Chantawee (2020). A permeabilidade ao vapor de água (WVP) foi determinada gravimetricamente de acordo com Garcia et al. (2014). A análise de cor foi realizada usando um colorímetro digital Minolta Chroma Meter CR-400 (Konica Minolta, Osaka, Japão), a diferença de cor total (ΔE) foi calculada. A capacidade da barreira à radiação UV foi avaliada seguindo a metodologia de Versino &

Garcia (2014), com modificações. A opacidade aparente (Po) da amostra foi medida conforme descrito por Abdillah & Charles (2021). A espessura foi determinada usando um micrômetro digital externo. As propriedades mecânicas dos filmes foram medidas usando um medidor de textura. Os ensaios foram realizados de acordo com Garcia et al. (2014). A resistência à tração (σ - MPa), alongamento na ruptura (ε - %) e módulo de Young (MPa) dos corpos de prova (2,5 x 5 cm) foram avaliados. Os espectros de FTIR foram obtidos em um espectroscópio infravermelho Thermo Fisher Scientific. A morfologia da superfície das amostras foi avaliada por microscópio eletrônico de varredura (MEV) (Fisher Scientific-FEI, República Tcheca). A perda de peso foi avaliada de acordo com Muley e Shangay (2020), com algumas modificações. Caracterização de morangos frescos revestidos, o teor de sólidos solúveis totais (SST) foi determinado pela avaliação da polpa dos frutos selecionados por meio de um refratômetro digital (Hanna Instruments, modelo HI96801). As análises foram realizadas em triplicata, e os resultados expressos em °Brix. A medição de pH foi adaptada de Muley & Shangay (2020). A determinação da cor foi determinada a partir da polpa dos frutos controle e revestidos. Os resultados foram submetidos à análise de variância (ANOVA) e teste de Tukey para comparação de médias ($p < 0,05$) utilizando o software Statistic 7.0 (StatSoft Inc., Tulsa, EUA).

RESULTADO E DISCUSSÃO. A adição de óleo de soja às soluções filmogênicas (2,5, 3,0 e 3,5) reduziu o valor de MC nos filmes quando comparados aos que não continham óleo (2,5C, 3,0C e 3,5C). No entanto, essa redução não foi suficiente para diferir significativamente entre eles ($p > 0,05$), onde esse percentual variou de 9,26±0,95 (3,0) a 11,43±2,25 (2,5C). Os resultados percentuais de SW dos filmes variaram de 27,55±5,37 (3,5) a 43,09±7,06 (3,5C), resultados que diferiram significativamente ($p > 0,05$). Essa diferença ocorre porque a formulação 3.5 possui óleo de soja. A formulação 3,5C não possui óleo, tendo assim mais hidroxilas disponíveis para interagir com as moléculas de água. As outras formulações não diferiram significativamente. Os valores percentuais de SD, para os filmes, variaram de 1346,58±78,73 a 2732,83±869,79, sem diferenças significativas ($p > 0,05$). A avaliação da WVP é um parâmetro importante para garantir as propriedades organolépticas de hortaliças e frutas armazenadas. Dos filmes avaliados, aqueles sem adição de óleo de soja (2,5 C, 3,0 C e 3,5 C) apresentaram diferenças significativas ($p > 0,05$) daqueles com adição de óleo (2,5, 3,0 e 3,5), este último com valores de WVP mais baixos. De acordo com a Tabela 2, os filmes que apresentaram maior barreira à luz UV foram 3,0 e 3,5. Por outro lado, os filmes 2,5, 3,0C e 3,5C não apresentaram diferença significativa ($p > 0,05$). O Po pode variar de acordo com os agentes formadores do filme, onde o aumento da concentração de mandioca, óleo e amido pode aumentar a opacidade dos filmes. Demonstre que o filme 2,5 apresentou o maior valor e 3,5C o menor valor de opacidade, enquanto 3,0, 2,5C e 3,0C apresentaram similaridade ($p < 0,05$). Esses resultados demonstram a aplicabilidade dos filmes 2,5, pois alcançaram a transparência desejável em comparação com outras formulações. Este valor de tendência pode ser correlacionado com a adição de óleo de soja e lecitina às formulações, maior para a formulação 3.5. A cor amarelada desses componentes se deve à presença de vitamina E e carotenóides em sua composição. A correlação é observada para os valores de ΔE^*, maiores quando a concentração de óleo e lecitina de soja na formulação filmogênica é elevada. A variação da espessura foi (0,067 a 0,157 mm) variando significativamente ($p < 0,05$). O filme 3,5C apresentou a maior espessura. Por outro lado, o menor foi registrado pelos 2,5 filmes. As propriedades mecânicas são de grande importância para muitas aplicações, incluindo embalagens de alimentos. Assim como observado em filmes contendo óleo de soja, onde o alongamento máximo do filme 3,0 foi de 2,766. Os espectros de FTIR dos filmes obtidos são mostrados, portanto, podemos inferir uma interação entre as moléculas de lecitina e amido com os demais componentes. Este fato pode ser atribuído à interação do óleo de soja com a lecitina (porção hidrofóbica), uma vez que a relação óleo de soja/lecitina é a mesma para as amostras. As características superficiais dos filmes compósitos foram avaliadas por MEV, como mostrado adicionalmente, observa-se que a maioria das amostras apresentam trincas em proporções diferentes, como observado em todas as imagens, exceto para a imagem referente ao filme 3.0. Como observado, os filmes 3,0 e 3,0C apresentam menor índice de trincas. Das soluções filmogênicas avaliadas inicialmente representadas na Tabela S1, apenas aquelas com adição de óleo de soja (2,5, 3,0 e 3,5) foram aplicadas como revestimento comestível em morangos frescos. Isso se deve aos resultados obtidos nas análises de caracterização e principalmente à influência da hidrofobicidade pela adição de óleo de soja. Portanto, essas três formulações e sem cobertura (morango controle - CS) foram aplicadas em morangos frescos. Os morangos foram armazenados e avaliados em temperatura ambiente (25±5°C) por 10 dias. Visualmente, a diferença entre o CS e as soluções 2,5, 3,0 e 3,5 demonstram a influência dos revestimentos na senescência dos frutos durante o armazenamento a 25±5 ºC. Os filmes com maior concentração de óleo e amido, respectivamente 3,0 e 3,5, apresentaram deterioração fisiológica significativa com o crescimento fúngico, devido à maior espessura desses filmes devido à maior concentração de amido e óleo de soja. A cobertura 2.5 estimulou melhor conservação do morango até o final da avaliação, devido à menor espessura e quantidade de óleo de soja, garantindo a conservação e trocas gasosas do morango. Na avaliação da perda de peso do morango, observou-se uma redução gradativa durante o armazenamento dos CS, 3,0 e 3,5, demonstrando que não atendem às características de conservação do morango. O revestimento 2.5 teve uma resposta melhor do que outras formulações durante todo o período de armazenamento. A avaliação do SST está relacionada à formulação do fruto 2,5 diferiu significativamente dos demais, pois manteve valores abaixo de 11 °Brix e pequena variação durante os 10 dias de avaliação. O pH do morango pode variar dependendo de outras condições, como clima, manejo e variedade, uma vez que a mesma cultivar pode apresentar valores de pH diferentes. O valor de pH do CS e morangos revestidos durante o armazenamento a 25±5 ºC por 10 dias é mostrado na Fig. 3c. Podemos observar que no dia 1, o pH variou de 3,26 a 3,36, sem diferença significativa nos valores, e demonstrou que as soluções filmogênicas utilizadas não alteram significativamente os valores de pH quando aplicadas em morangos. Em todos os parâmetros, a variação da cor da polpa dos morangos revestidos não apresentou diferenças significativas em relação ao CS devido ao revestimento possuir propriedades ópticas de transparência, sendo pronunciada a cor natural dos morangos, pois a solução aderiu uniformemente à sua superfície. Outros fatores que podem contribuir para o aumento da vermelhidão dos morangos foram a concentração de sua concentração de SST e a estabilidade de seus pigmentos (antocianinas) causada pela perda de peso (água). A amostra CS foi a mais impactada em relação a esses fatores, além do processo de deterioração estar mais avançado.

CONCLUSÃO. As formulações com adição de óleo de soja demonstraram eficiência diante das características avaliadas nos filmes por este método de casting. O óleo de soja emulsifica na rede do filme, diminuindo a disponibilidade de hidroxilas livres nas ligações de hidrogênio. Foi possível obter uma vida útil maior, de 3 dias (SC) a 10 dias (2,5) sob armazenamento a 25±5 ºC. A aplicação da formulação 2.5 atingiu a manutenção da

qualidade, provocou desaceleração no metabolismo e deterioração fisiológica dos morangos, indicando ser uma alternativa promissora para reduzir sua perecibilidade, além de diminuir as perdas econômicas. No geral, a aplicação de revestimentos mostrou-se inovadora ao prolongar a vida útil dos morangos para 10 dias, reduzindo sua perecibilidade, deterioração fisiológica e mantendo suas propriedades físicas inalteradas.
Palavras-chave: Filmes compostos. Lipídios. Óleo de soja. Conservação de morango.

EDIBLE COATINGS BASED ON CASSAVA STARCH INCORPORATING SOYBEAN OIL: POTENTIAL APPLICATION FOR PROLONGING THE SHELF LIFE OF STRAWBERRIES (*Fragaria ananassa*) CV SAN ANDREAS

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Abstract

Strawberry is a non-climacteric pseudofruit, highly perishable, with significant losses in its production process. The application of edible coatings becomes a promising alternative for preserving strawberries. In this context, the objective of this work was to develop a filmogenic solution of cassava starch with the incorporation of oil and soy lecithin, characterized by the casting method, in addition to applying them as a coating on fresh strawberries. Thus, the barrier, mechanical and optical properties, water resistance, functional groups, and morphology of the formed structure were measured. The results demonstrate that the presence of soy oil and lecithin promotes the rearrangement of polymeric bonds, as it reduces the availability of hydroxyls. In addition to acting as a protective layer to maintain quality, decrease gas exchange and mass loss, thus delaying physiological deterioration, when applied to strawberries. The combination of starch, lecithin, and soy oil provides adequate integrity for storage at room temperature 25±5 ºC.
Keywords: Composite films. Lipids. Soybean oil. Strawberry conservation.

1. Introduction

Strawberry is a non-climacteric pseudofruit, of considerable commercial and nutritional importance that adapts to various environmental conditions of cultivation worldwide, and its world production in 2019 reached almost 8.9 million tons (Yang et al., 2022). However, strawberries are highly perishable and susceptible to mechanical damage, physiological deterioration, water loss, and decomposition, thus altering their sensory characteristics and physicochemical composition. For this reason, strawberry losses are high from harvest to distribution, generally having a postharvest shelf life of 3-5 days at room temperature (Muley & Shingal, 2020).

The significant value loss of fruit waste is mainly due to high perishability. As an alternative to minimize the high perishability and increase the shelf life of fruits, a lot of research has been emerging in the scope of the use of biodegradable films and coatings edible to reduce the problems faced in production and commercialization (Gómez-Contreras et al., 2021). This technology can change water loss, permeability to respiratory gases, and oxidative stress, among other adversities (Jayakody, Vanniarachchy, &

Wijesekara, 2022). Therefore, applying films and coatings edible becomes a promising alternative, acting in the conservation of strawberries.

Films and coatings have different classifications in terms of their application, but they can have the same production method. Films are independent structures, performed by the casting method of the biopolymer solution, subsequently applied to the separated food. Meanwhile, coatings can be emulsions or suspensions enforced directly on the food's surface, which after drying becomes a thin film. To improve or modify the basic functionality, the employ of lone or composite materials are used in their formulations (Dhumal & Sarkar, 2018).

Polysaccharides, proteins, and lipids are used as developing systems for films and edible coatings. Natural polymers have bioactive attributes, capable of preserving the quality of food products. Despite presenting benefits individually, they enable the use of combinations to improve their functions (Amin et al., 2021).

Cassava starch (a polysaccharide), which is hydrophilic, has the characteristics of nutrient preservation, a barrier against adverse effects, and low mechanical resistance (Li et al., 2020). However, plasticizing agents are essential to improve flexibility, compatibility, and stability among hydrophilic biopolymer chains. The plasticizing agents can incorporate glycerin and polyvinyl alcohol (PVOH) (Cazón, Velazquez, & Vázquez, 2020). Furthermore, meeting the existing needs in the formulation in relation to the barrier to moisture loss of the fruit, lipids and proteins can be included as hydrophobic agents in the incorporation into the hydrocolloid matrix (Kocira et al., 2021).

The combination of these components can form coatings with better functionality, ensuring the quality of the fruit. Compared to conventional disposable packaging, which generates a lot of waste and decomposes with time, coatings add value and reduce waste generation using renewable resources and ecologically correct components. In addition to the traditional protection and inert barrier to the external environment, coatings interact with the surface of the food, ensuring its conservation (Pinto et al., 2021).

The incorporation of lipids in edible coatings has been carried out by the emulsion process, with the addition of monoglycerides, diglycerides, triglycerides, and lecithin, able to stabilize dispersed systems (Gutiérrez-Jara et al., 2020). The activities of these substances, even in small amounts, offer properties in the physical (mechanical) and chemical barriers, factors associated with their polarity (Gutiérrez-Jara et al., 2020; Yousuf, Sun, & Wu, 2021). Different materials, such as cassava starch, soybean oil, soy lecithin, glycerin, and PVOH, were used for the elaboration of films and coatings edible for application in fresh strawberries in the conservation of quality. In this context, the present study aims to develop and characterize edible films by the casting method, in addition to evaluating your application as a coating on fresh strawberries minimizing their perishability, and evaluating their physiological deterioration, increasing their shelf life under environmental conditions of storage 25±5 ºC.

2. Materials and methods

2.1. Materials

The films and coatings were produced from cassava starch (87.1% purity) donated by Podium Alimentos (Tamboara, Brazil), soybean oil and soy lecithin kindly donated by Cocamar (Maringá, Brazil), polyvinyl alcohol (PVOH), and double-distilled glycerin purchased from Êxodo Científica (Sumaré, Brazil). The materials were used as received, without additional purification steps.

For the coating trials, were acquired fresh strawberries (*Fragaria ananassa*) cv. San Andreas from a producer located in the city of Ivaiporã, Brazil (24°19'58.8"S.

51°44'21.2"W). The fruits were harvested when they reached 3/4 of the surface red color, selected for size uniformity, absence of mechanical damage, stains, or diseases.

2.2. Film production and application of coating on strawberries

The production of the films developed by the casting method and the coatings by solutions filmogenic according to the formulations presented in Table 1.

Table 1 Formulations used in the preparation of the films and coatings.

Formulations[c]	Distilled water[a] (%)	Cassava starch[b] (%)	Soybean oil (%)	Soy lecithin (%)	Glycerin (%)	PVOH (%)
2.5	95.6	2.5	0.10	0.30	0.75	0.75
3.0	94.9	3.0	0.15	0.45	0.75	0.75
3.5	94.2	3.5	0.20	0.60	0.75	0.75
2.5C	95.5	2.5	-	0.30	0.75	0.75
3.0C	97.7	3.0	-	0.45	0.75	0.75
3.5C	94.0	3.5	-	0.60	0.75	0.75

a: volume of the solutions filmogenic (Petri dish D=150mm)
b: 2.5, 3.0, 3.5 considering the starch's purity degree.
c: 2.5, 3.0, 3.5: formulations with the addition of soybean oil; 2.5C, 3.0C, 3.5C: formulations without the addition of soybean oil.

An emulsion was formed between soybean oil, distilled water, and soy lecithin, under magnetic stirring, separately and after being added. The starch, previously dissolved in distilled water, was added in sequence under continuous stirring. After the mixture was homogeneous, heated to 90 ± 2 °C for starch gelatinization. Subsequently, the solution was transferred to an ultrasonic bath (ELMA, Elmasonic P, São Paulo, Brazil) at an 80 kHz frequency for 10 min to remove air bubbles caused by the stirring process. Then, the solution filmogenic was reserved for application by immersion in strawberries. For the production of the films, this same solution was poured into polyethylene Petri dishes (150 x 15 mm), and placed in an oven with air circulation at 40 ± 2 °C for 16 h, to promote the drying of the films. After the drying process, the films were detached from the Petri dishes, stored in appropriate packaging, and stocked in a desiccator for further analysis.

For application on strawberries, 80 fruits were selected according to the absence of physiological factors, free of visible stains, with uniformity of size and apparent color. All fruits were sanitized by immersion in 0.1% sodium hypochlorite solution, rinsed, and dried at room temperature. Subsequently, 20 strawberries were used as controls without the coating, while the others (60) were immersed in the solutions filmogenic for about 20 s and dried for 24 h at 25.05±1.05 ℃ (28% relative humidity, RH). The development of the formulations is illustrated in Figure 1.

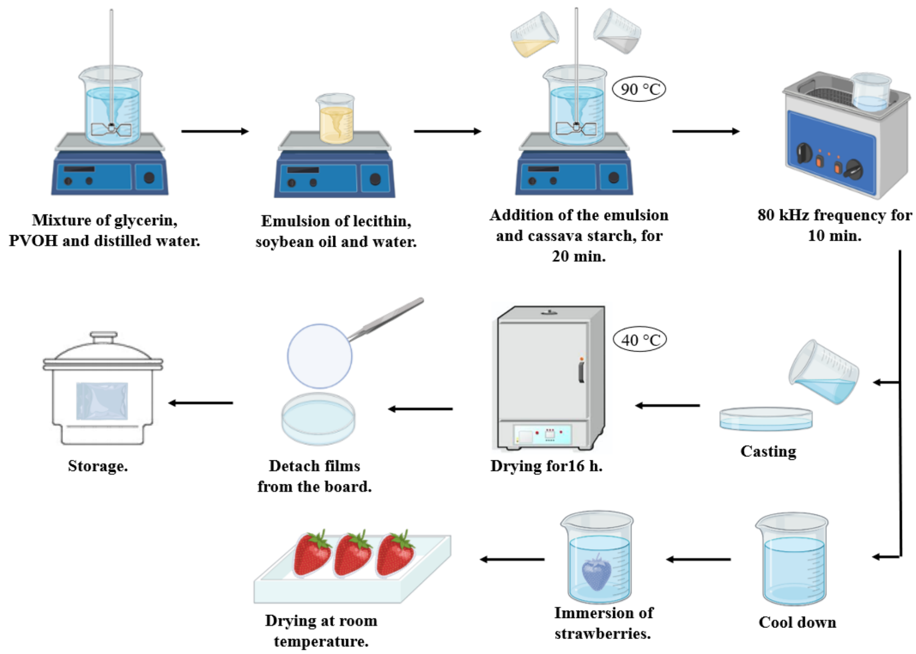

Figure 1. Production scheme of solutions filmogenic and application.

2.3. Films' Characterization

2.3.1. Moisture content (MC)

The moisture contents (MC) were determined gravimetrically, according to Versino & Garcia (2014), where cut films with measurements of 2 x 2 cm were taken to an oven at 105 °C until constant weight. The samples were evaluated in triplicate, and the results expressed as a percentage (%) of the moisture content.

2.3.2 Solubility in water (SW)

The solubility in water (SW) of the films was determined according to the methodology described by Ma et al. (2017). Dry films, used for moisture determination, were weighed to obtain the initial weight (Wi) and immersed in a Falcon tube (50 mL) containing 30 mL of distilled water for 24 h at 25 °C. The resulting solution was purified through previously weighed filter paper. Then, the filter paper containing the residual sample was taken to an oven at 105 °C for 24 h to obtain the final weight (Wf). Measurements were in triplicate. Was calculated the percentage of solubility in water used Eq. 1:

$$SW(\%) = \left(\frac{Wi - Wf}{Wi}\right) x100 \qquad (1)$$

Where, Wi and Wf are initial and final weight, respectively.

2.3.3. Swelling degree (SD)

The swelling degree (SD) was measured gravimetrically according to Riyajan, & Chantawee (2020), with minor modifications. Briefly, 0.20 g of the dry film was placed in a Falcon tube containing 30 mL of distilled water and kept at 25 °C for 24 h. SD% was determined in triplicate applying Eq. 2.

$$SD\ (\%) = \frac{(Ws - Wd)}{Wd} x100 \qquad (2)$$

Where, Ws and Wd are the weight of the swollen and dry sample, respectively.

2.3.4. Water vapor permeability (WVP)

Water vapor permeability (WVP) was determined gravimetrically according to Garcia et al. (2014), with modifications. Initially, the films were cut to the shape of the respective Teflon permeation cups in duplicate. The film samples were weighed and fixed on the surface of a Teflon permeation cup containing a saturated solution of magnesium chloride (RH, 33%). Were conditioned in cups in a desiccator at 25 °C containing saturated sodium chloride solution (RH, 75%). They were weighed at 2 h intervals for 24 h. Changes in mass gain (m) were plotted against time (t) to obtain the slope (m/t) of the linear regression curve. Thus, the water vapor permeability ratio (WVPR) was calculated by Eq. 3:

$$WVPR = \frac{m}{t} x \frac{1}{A} \qquad (3)$$

Where, m/t is the slope of the curve, and A is the available area of the film.

Followed by the determination of WVP, calculated by Eq. 4:

$$WVP = \frac{WVPR\ x\ st}{sp\ (RH_1 - RH_2)} \qquad (4)$$

Where, st is the average film thickness (mm), sp is the saturation pressure of water vapor at the test temperature (Pa), RH_1 is the relative humidity of the desiccator and RH_2 is the relative humidity inside the permeation cell.

2.3.5. Color determination

Color analysis was performed using a Minolta Chroma Meter CR-400 digital colorimeter (Konica Minolta, Osaka, Japan), evaluating the brightness (L*) parameters from black to white varying from 0 to 100, a* determines the variation from red (+a*) to green (−a*), while the b* axis shows the variation from yellow (+b*) to blue (−b*). The total color difference (ΔE) was calculated through Eq. 5.

$$\Delta E = \sqrt{(L - L^*)^2 + (a^* - a)^2 + (b^* - b)^2} \qquad (5)$$

Where, L* (93.79), a* (-0.97) and b* (4.27) were the color parameters of the white plate pattern Konica.

2.3.6. Barrier to UV radiation

The capacity of the barrier to UV radiation was evaluated by following the methodology of Versino & Garcia (2014), with modifications. The films were cut into rectangles 10 x 40 mm, transferred to a quartz cuvette, and the transmittance was interpreted in triplicate, with a spectrophotometer (Thermo Fisher Scientific, Genesys 10-S, Finland). A quartz cuvette without a film sample was used as a reference control. The transmittance spectrum was evaluated at 290 nm.

2.3.7 Apparent opacity (Po)

The apparent opacity (Po) of the sample was measured as described by Abdillah & Charles (2021). Pieces of the films were cut with measurements of 10 x 40 mm and later evaluated using a spectrophotometer (Thermo Fisher Scientific, Genesys 10-S, Finland) at 550 nm. A quartz cuvette without a film sample was used as a reference control. The opacity of the films was determined by Eq. 6.

$$\mathrm{Po} = \frac{\mathrm{Abs}_{550}}{\mathrm{X}} \qquad (6)$$

Where, Abs550 is the absorbance (550 nm) and X is the film thickness (mm).

2.3.8. Thickness

The thickness was determined using a digital external micrometer (0-25 mm with a resolution of 0.001 mm/IP40/Digimess) by measuring the thickness of the films at fifteen random points for each of the samples and calculating their mean value (mm).

2.3.9 Mechanical properties

The mechanical properties of the films were measured using a texture meter (model TA.TX2 plus, Surrey, England). Assays were performed according to Garcia et al. (2014). Tensile strength (σ - MPa), elongation at break (ε - %), and Young's modulus (MPa) of specimens (2.5 x 5 cm) were evaluated.

2.3.10. Fourier transform infrared spectroscopy (FTIR)

FTIR spectra were obtained on a Thermo Fisher Scientific infrared spectroscope (model Nicolet iN10, USA). The spectra were obtained in the range of 4000 and 650 cm^{-1} with a resolution of 4 cm^{-1} and 128 scans. For the films, the Fourier transform infrared spectroscopy-Attenuated total reflectance (FTIR-ATR) mode was used, using a crystal of zinc selenide (ZnSe), the agents filmogenic, the FTIR-Potassium Bromate (FTIR-KBr) mode was applied, with a ratio of 1:100 (w/w) (sample /KBr).

2.3.11. Scanning electron microscopy (SEM)

The samples' surface morphology was evaluated by Scanning electron microscope (SEM) (Fisher Scientific-FEI, Czech Republic). The films surface was sputter-coated with a gold layer (≈50 nm) using a metallizer (SCD 050, Bal-Tec, Obermattstrasse, Switzerland). The sputter-coating procedure was performed by applying a 60 mA current for 120 s in a high vacuum. This procedure increases the sample conductivity to allow SEM visualization. The images were acquired under 2000x magnification and at an accelerating voltage of 12.5 kV.

2.4. Characterization of coated fresh strawberries

2.4.1. Weight loss

The weight loss was evaluated according to Muley and Shangay (2020), with some modifications. Briefly, the weight of the control and coated strawberries was recorded every 2 days, starting from day 0 to day 10. The weight loss differential was calculated using Eq. 7, expressed as a percentage of the triplicate.

$$Weight\ loss\ (\%) = \frac{W0 - Wn}{W0}\ x\ 100 \qquad (7)$$

Where, W_0 and Wn are strawberries' initial and final weight.

2.4.2. Total Soluble solids (TSS) content

The total soluble solids (TSS) content was determined by evaluating the pulp of the selected fruits using a digital refractometer (Hanna Instruments, model HI96801). The analyzes were performed in triplicate, and the results expressed in °Brix.

2.4.3. pH

The pH measurement was adapted from Muley & Shangay (2020). Briefly, pulp strawberries (5 g) were put in a beaker where 50 mL of distilled water was added. After the mixture was homogenized and filtered. Filtrate pH measurements in triplicate were performed using a digital pH meter (mod Luca-210, Brazil).

2.4.4. Color determination

The color determination was determined from the pulp of the control and coated fruits, by the same method proposed above (2.3.5 section).

2.5. Statistical analysis

The results were submitted to analysis of variance (ANOVA) and Tukey's test to compare means ($p < 0.05$) using the Statistic 7.0 software (StatSoft Inc., Tulsa, USA).

3. Results and discussion

3.1. Films' characterization

3.1.1. Wettability parameters

The wettability behavior of films in different formulations was evaluated in terms of MC, SW, SD, and WVP are shown in Table 2.

Table 2 Wettability parameters.

Formulations	MC%	WS%	SD%	WVP [g m (Pa m^2 $s)^{-1}$]
2.5	9.70 ± 0.72^{a}	35.23 ± 5.76^{ab}	2705.49 ± 896.51^{a}	$9.17x10^{-12} \pm 1.41x10^{-13d}$
3.0	9.26 ± 0.95^{a}	36.79 ± 4.74^{ab}	2464.34 ± 938.86^{a}	$1.09x10^{-11} \pm 2.75x10^{-12cd}$
3.5	9.90 ± 0.78^{a}	27.55 ± 5.37^{b}	1605.01 ± 782.47^{a}	$4.44x10^{-11} \pm 4.29x10^{-11bc}$
2.5C	11.43 ± 2.25^{a}	43.09 ± 7.06^{a}	1346.58 ± 78.73^{a}	$1.51x10^{-11} \pm 3.87x10^{-12ab}$
3.0C	11.37 ± 0.76^{a}	35.61 ± 3.33^{ab}	1422.48 ± 239.59^{a}	$1.69x10^{-11} \pm 1.57x10^{-12ab}$
3.5C	11.35 ± 0.60^{a}	31.44 ± 1.73^{ab}	2732.83 ± 869.79^{a}	$1.94x10^{-11} \pm 5.60\ x10^{-12a}$

MC (%): moisture content; WS (%): solubility in water; SD (%): swelling degree (%); WVP: water vapor permeability. Results presented in mean ± standard deviation. [a,b,c],[d]Different letters in the same column indicate significant differences ($p \leq 0.05$).

The addition of soybean oil to the solutions filmogenic (2.5, 3.0, and 3.5) reduced the value of MC in the films when compared to those that did not contain oil (2.5C, 3.0C, and 3.5C) (Table 2). Gómez-Contreras et al. (2021) mention that the incorporating of hydrophobic substances in a polysaccharide matrix tends to reduce possible interactions between water and the functional groups of the polymer, thus facilitating their elimination during the drying process of the films. However, this reduction was not enough to significantly differ between them ($p > 0.05$), where this percentage ranged from 9.26±0.95

(3.0) to 11.43±2.25 (2.5C). These results agree with Désiré et al. (2021), which obtained a reduction in moisture content after the addition of peanut oil and soy lecithin in edible starch-based films, yielding results from 15.99%–11.43% to 14.24%–10.66%.

The SW percentage results (Table 2) of the films ranged from 27.55±5.37 (3.5) to 43.09±7.06 (3.5C), results that differed significantly ($p > 0.05$). This difference occurs because formulation 3.5 has soybean oil. The soybean oil is emulsified in the film network, reducing the availability of hydroxyls to form hydrogen bonds with water, thus reducing the solubility of this material. The 3.5C formulation has no oil, thus having more hydroxyls available to interact with water molecules. The other formulations did not differ significantly. SW is an essential factor for the application of this material, applied as a coating on fruits because coatings with high solubility could dissolve easily (Ma et al., 2017).

Starch, when present in an aqueous solution and this is heated, the hydrogen bonds are broken, and the granule begins to absorb water and swell (60-70 °C), simultaneously releasing amylose into the medium until it breaks (90 °C) which contributes to the increase in viscosity, this can be calculated before the SD rupture. It is important to note that for each type of starch, there is a range of gelatinization Kocira et al. (2021). The percentage values of SD (Table 2) for the films ranged from 1346.58±78.73 to 2732.83±869.79, with no significant differences ($p > 0.05$). These values are consistent, as reported by Cazón, Velazquez, & Vázquez (2020).

The WVP evaluation is an important parameter to guarantee the organoleptic properties of stored vegetables and fruits. Edible films and coatings should act as an effective semi-permeable barrier to water vapor and surrounding atmospheric gases, minimizing oil transfer from the fruit membrane and its gas exchange. Of the evaluated films (Table 2), those without the addition of soybean oil (2.5 C, 3.0 C, and 3.5 C) showed significant differences (p > 0.05) from those with the addition of oil (2.5, 3.0, and 3.5), the latter with lower WVP values. Therefore, films and coatings made from soybean oil emulsions and soybean lecithin in their composition may effectively resist to water vapor migration. Previous studies found that the WVP of films decreases with the incorporation of canola oil (Syarifuddin, HasmiyaniDirpan, & Mahendradatta, 2017), sunflower oil (Parreidt et al., 2019), cinnamon and ginger oil (Atarés, Bonilla, & Chiralt, 2010). Applying a hydrophobic surface limits water vapor migration from within the film matrix (Muley & Singhal, 2020).

3.1.2. Optical properties and barriers to UV radiation

The optical characteristics of films are fundamental factors aimed at consumer acceptability. However, films and coatings with the addition of lipid compounds can interfere with their transparency (Yousuf, Sun, & Wu, 2021). Consequently, this influences the delay in the degradation of food components sensitive to ultraviolet radiation (UV) (Cazón, Velazquez, & Vázquez, 2020). Table 3 highlights the films' barrier UV radiation, opacity, and color.

Table 3 Optical properties and barrier UV radiation.

Formulations	Barrier UV	Po (A/mm)	L*	a*	b*	ΔE
2.5	0.15 ± 0.01^{bc}	2.38 ± 0.02^{a}	93.05 ± 0.01^{ab}	-1.00 ± 0.02^{a}	5.92 ± 0.01^{c}	3.46 ± 0.04^{c}
3.0	0.29 ± 0.03^{a}	0.99 ± 0.03^{c}	92.92 ± 0.07^{bc}	-1.11 ± 0.03^{b}	6.19 ± 0.01^{b}	4.59 ± 0.09^{b}
3.5	0.28 ± 0.04^{a}	1.07 ± 0.03^{b}	92.76 ± 0.02^{c}	-1.21 ± 0.01^{c}	6.44 ± 0.05^{a}	$5,78 \pm 0.02^{a}$
2.5C	0.16 ± 0.01^{b}	0.96 ± 0.03^{c}	93.10 ± 0.09^{a}	-1.74 ± 0.02^{f}	5.14 ± 0.00^{f}	2.04 ± 0.11^{d}
3.0C	0.11 ± 0.02^{c}	0.95 ± 0.04^{c}	91.72 ± 0.09^{d}	-1.48 ± 0.02^{e}	5.31 ± 0.01^{e}	3.41 ± 0.07^{c}
3.5C	$0.12 \pm 0.02b^{c}$	0.65 ± 0.01^{d}	91.88 ± 0.01^{d}	-1.37 ± 0.02^{d}	5.47 ± 0.01^{d}	3.50 ± 0.03^{c}

Po: Opacity (absorbance/thickness); Color determination (L*, a*, b* e ΔE). Results presented in mean ± standard deviation. [a,b,c,d]Different letters in the same column indicate significant differences ($p \leq 0.05$).

According to Table 3, the films that presented a higher barrier to UV light were 3.0 and 3.5. On the other hand, the films 2.5, 3.0C, and 3.5C did not present a difference significantly ($p > 0.05$). The values indicate that lipids provide a more significant barrier to UV radiation, which is essential for coatings on foods since this radiation can cause oxidation and deterioration of compounds in fruits mediated by light (Pinto et al., 2021). This effect is attributed to the combination of compounds during the process of forming the solutions filmogenic by chain rearrangements and thickness variation, thus promoting the adsorbent properties of water molecules in the UV region Cazón, Velazquez, & Vázquez, (2020).

The Po can vary according to the film forming agents, where increasing the concentration of cassava, oil, and starch can increase the films' opacity. The results in Table 2 demonstrate that film 2.5 presented the highest value and 3.5C had the lowest opacity value, while 3.0, 2.5C, and 3.0C showed similarity ($p < 0.05$). These results demonstrate the applicability of the 2.5 films, as they achieved desirable transparency compared to other formulations. Pinto et al. (2021) mention that by reducing the transmittance of UV light, there is an increase in opacity, which correlates with the concentrations of essential oil used, thus confirming our results.

The results of the color determination of the films are presented in Table 3. The evaluated parameters demonstrate that the luminosity (L*) of the formulations was high as they approached 100, and this tendency to white is justifiable by the transparency of the films and the low concentration of pigmented raw materials dispersed in the components filmogenic. The negative a* value indicates a tendency to green values ranging between -

1.00 and -1.74, that is, values close to zero, which are considered of low trend, justified by the use of refined oil (minimum concentration of chlorophyll) and soy lecithin in small concentrations. The positive parameter b* (blue to yellow) indicates that the films tend to be yellow, as demonstrated in Figure 2. This trend value can be correlated with adding soy oil and lecithin to formulations, higher for formulation 3.5. The yellowish color of these components is due to the presence of vitamin E and carotenoids in their composition. The correlation is seen for the values of ΔE *, higher when the concentration of oil and soy lecithin in the filmogenic formulation is raised. These values are consistent with those observed by (Muley & Singhal, 2020).

Figure 2. Appearance of films. 2.5, 3.0, 3.5: formulations with the addition of soybean oil; 2.5C, 3.0C, 3.5C: formulations without the addition of soybean oil.

3.1.3. Thickness and mechanical properties

The films' thickness and mechanical properties are essential for applying coatings on food, and the results are described in Table 4.

Table 4 Thickness and mechanical properties of the films.

Formulation	Thickness	σ (Mpa)	ε (%)	Σ (Mpa)
2.5	0.067 ± 0.014^{d}	0.003 ± 0.001^{bc}	2.271 ± 0.569^{ab}	0.135 ± 0.004^{b}
3.0	0.095 ± 0.014^{c}	0.005 ± 0.001^{a}	2.766 ± 0.276^{a}	0.209 ± 0.031^{ab}
3.5	0.128 ± 0.011^{b}	0.005 ± 0.001^{ab}	$2.065 \pm 0{,}613^{ab}$	0.245 ± 0.039^{a}
2.5C	0.124 ± 0.017^{b}	0.003 ± 0.002^{c}	1.394 ± 0.376^{b}	0.146 ± 0.068^{b}
3.0C	0.135 ± 0.015^{b}	0.005 ± 0.001^{ab}	2.065 ± 0.613^{ab}	0.251 ± 0.034^{a}
3.5C	0.157 ± 0.017^{a}	0.005 ± 0.002^{ab}	2.033 ± 0.768^{ab}	0.280 ± 0.043^{a}

σ (MPa): tensile strength; ε (%): elongation at break; Σ (MPa): Young's modulus. Results presented in (mean ± standard deviation). [a,b,c] Different letters in the same column indicate significant differences ($p \leq 0.05$).

The thickness variation was (0.067 to 0.157 mm) varying significantly ($p < 0.05$). The 3.5C film exhibited the greatest thickness. On the other hand, the smallest was recorded by the 2.5 films. The decrease in thickness correlated with the reduction in the polysaccharide concentration. In this way, it can affect the entry of water into the polymer matrix because fewer amylose and amylopectin molecules are available, thus reducing the plasticizing effect of the films (Gomez-Contreras, et al., 2021).

Mechanical properties are of great importance for many applications, including food packaging. The control films (without soybean oil) and films with soybean oil presented similar tensile strength values, as observed in Table 4. On the other hand, the films containing soybean oil present higher elongation values at the break when compared to the films containing soybean oil films without soybean oil. With this, we can infer that soybean oil plays a plasticizing action in the films. It is worth mentioning that plasticizers are allocated among the macromolecular chains (PVOH and starch, for example). Indeed, it reduces intermolecular interactions and increases the free volume among the chains. This fact results in a more flexible and extensible material, as observed in films containing soybean oil, where the maximum elongation of the 3.0 film was 2.766%. Finally, adding soybean oil to the films makes the materials softer (less rigid) than films without soybean oil, showing that soybean oil, showing that soybean oil plays an essential role in mechanical properties.

3.1.4. Evaluation of compound interactions

In Figure 3 are presented the FTIR spectra and SEM images. From this Figure, the interactions among materials used to obtain the films can be evaluated.

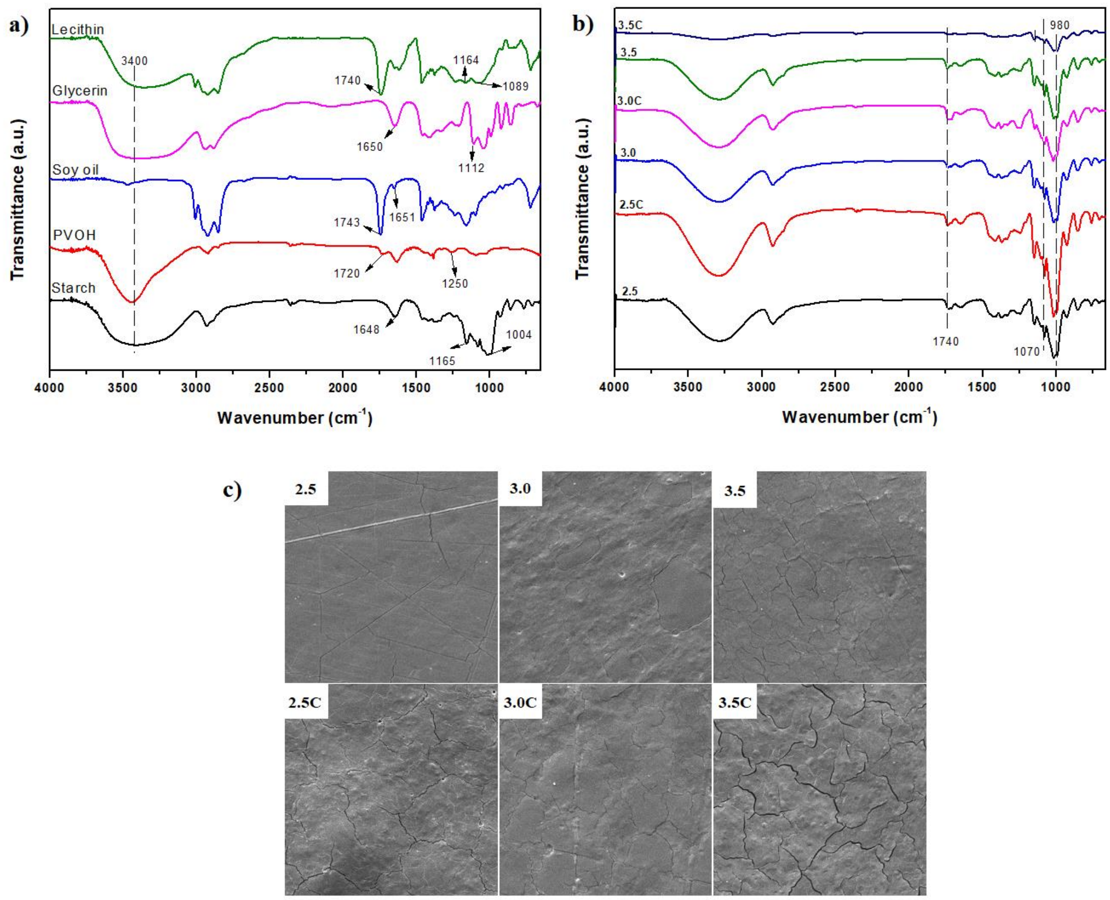

Figure 3. (a) FTIR spectra of films. (b) FTIR spectra of solutions filmogenic components. (c) SEM images at 2000x magnification.

The FTIR spectra of the agents filmogenic are demonstrated in Figure 3b. A communal band was observed in the spectrum (3400 cm^{-1}), which corresponds to the stretching of the OH groups. This band has a lower intensity in the spectrum of soybean oil. In the region from 1743 to 1720 cm^{-1} of the spectrum of soybean oil, lecithin, and PVOH, the characteristic stretching bands of the non-hydrolyzed C-O, C=O, and C=O groups were observed, respectively (Hidayah, 2018; Siyal et al., 2020; Silva, Quintella, & Meira, 2017; Cruz, 2020). The bands in the region between 1651 and 1648 cm^{-1} of the spectra of soybean oil, glycerin, and starch were attributed to C=C vibration, water bending, and bending of the C-O groups associated with water, respectively. However, we cannot neglect the carboxylic groups (C=O; ketones and aldehydes) that absorb in 1650 cm^{-1} (Lopes, 2019). These groups can be obtained from glycerol's degradation (glyceraldehyde and dihydroxyacetone) (Lopes, 2019). The bands between 1250 and 1112 cm^{-1} of the PVOH, Starch, lecithin, and glycerin spectra were assigned to O-C-O acetate bonds, C-O-C asymmetric stretching, C-O vibrational stretching, and primary alcohol stretching (Cruz, 2020; Abdullah, Chalimah, Primadona, & Hanantyo, 2018; Hidayah, 2018). The band at 1089 cm^{-1} was attributed to the vibrational stretching of the C-C groups (Hidayah, 2018; Siyal et al., 2020).

FTIR spectra of the films obtained are shown in Figure 3a. A shift in the band is observed at 1738 cm^{-1} when compared to agents filmogenic (Figure 3b). Such a band was attributed to the stretching of the C=O groups. It is indicative of interactions of these groups with others, such as OH, present in the other components. Additionally, films' spectra (without soybean oil) decrease the intensity of the bands between 980-1070 cm^{-1} when the amounts of lecithin and starch increase. Therefore, we can infer an interaction between the lecithin and starch molecules with the other components. On the other hand, when soybean oil is incorporated into the films, the intensity of this region does not show significant changes when compared to the different films containing soybean oil. This fact can be attributed to the interaction of soybean oil with lecithin (hydrophobic portion) since the soybean oil/lecithin ratio is the same for the samples.

The surface characteristics of the composite films were evaluated by SEM, as shown in Figure 3c. In general, it is observed in the SEM images that the surfaces of the films are compact, irregular, and do not present phase separation, indicating an effective interaction between the components. However, in some samples, small globular clusters are observed. Such irregularities are possibly caused by incomplete gelatinization of the starch. Additionally, it is observed that most samples have cracks in different proportions, as observed in all images, except for the image referring to the 3.0 film. As observed, the 3.0 and 3.0C films have a lower rate of cracks. This fact can be related to the higher elongation of these samples concerning the others.

3.2. Characterization of coated fresh strawberries

3.2.1. Application and appearance of strawberries

The appearance of films and fresh strawberries with and without coating is shown in Figure 4.

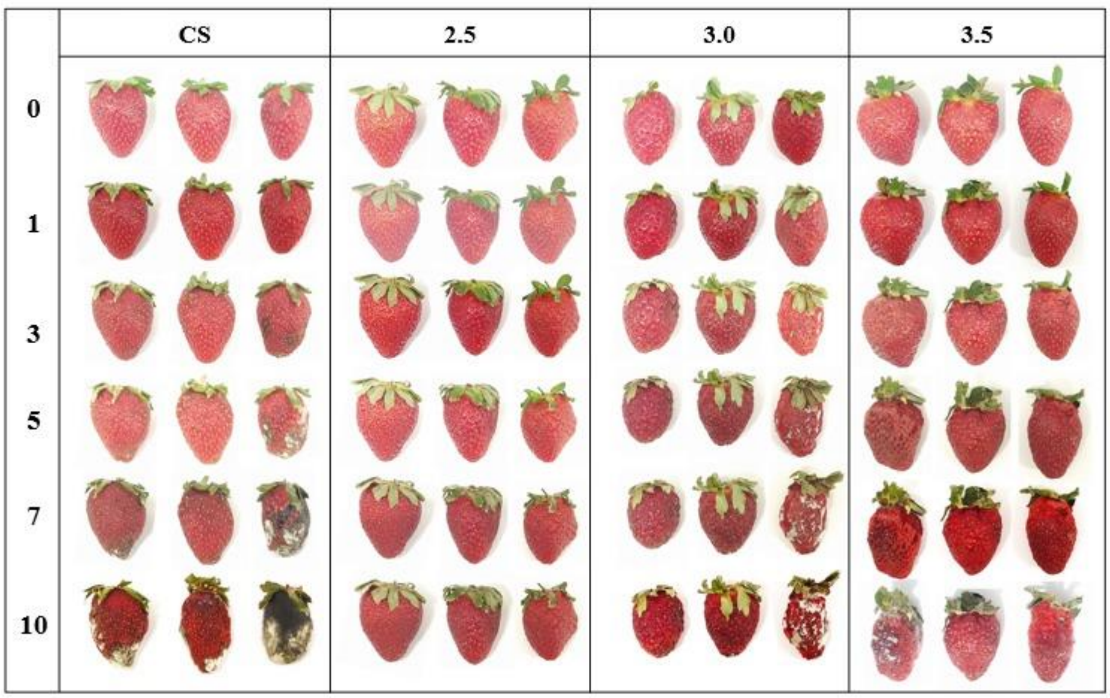

Figure 4. Visual evaluation of the films and fresh strawberries after immersion in a solutions filmogenic, for a period of 10 days under ambient conditions of 25 ± 5 °C. CS: control strawberry; 2.5, 3.0, 3.5: strawberries coated with a film-forming solution containing soybean oil.

Of the evaluated solutions filmogenic initially represented in Table 1, only those with the addition of soybean oil (2.5, 3.0, and 3.5) were applied as an edible coating on fresh strawberries. This is due to the results obtained in the characterization analysis and mainly the influence of hydrophobicity by the addition of soybean oil. Therefore, these three formulations and without coating (control strawberry - CS) were applied to fresh strawberries. The characterization analyzes of the strawberries carried out the day after the coating step. Strawberries were stored and evaluated at room temperature (25±5 °C) for 10 days.

Visually, the difference between the CS and solutions 2.5, 3.0, and 3.5 demonstrate the influence of coatings on fruit senescence during storage at 25±5 ºC. The films with the highest concentration of oil and starch, respectively 3.0, and 3.5, showed significant physiological deterioration with fungal growth (Figure 4), is due to the greater thickness of these films due to the higher concentration of starch and soybean oil, thus preventing the passage of water and fruit gas exchange (Gomez-Contreras, et al., 2021). As for the CS, they showed an accelerated deterioration and wilting, caused by excessive transpiration of the fruit (Muley & Shingal, 2020). Coating 2.5 stimulated better conservation of the strawberry until the end of the evaluation, is due to the lower thickness and amount of soybean oil, guaranteeing the conservation and gas exchange of the strawberry. The application of this formulation can maintain the characteristics of the fruits, being a promising alternative to reduce the perishability of the strawberry during storage (Kocira et al., 2021).

3.2.2 Evaluation of strawberry storage

The evaluation of the storage of fresh strawberries under environmental conditions of 25±5 °C, was performed by the weight loss, TSS content and pH of the strawberries, is represented in Figure 5.

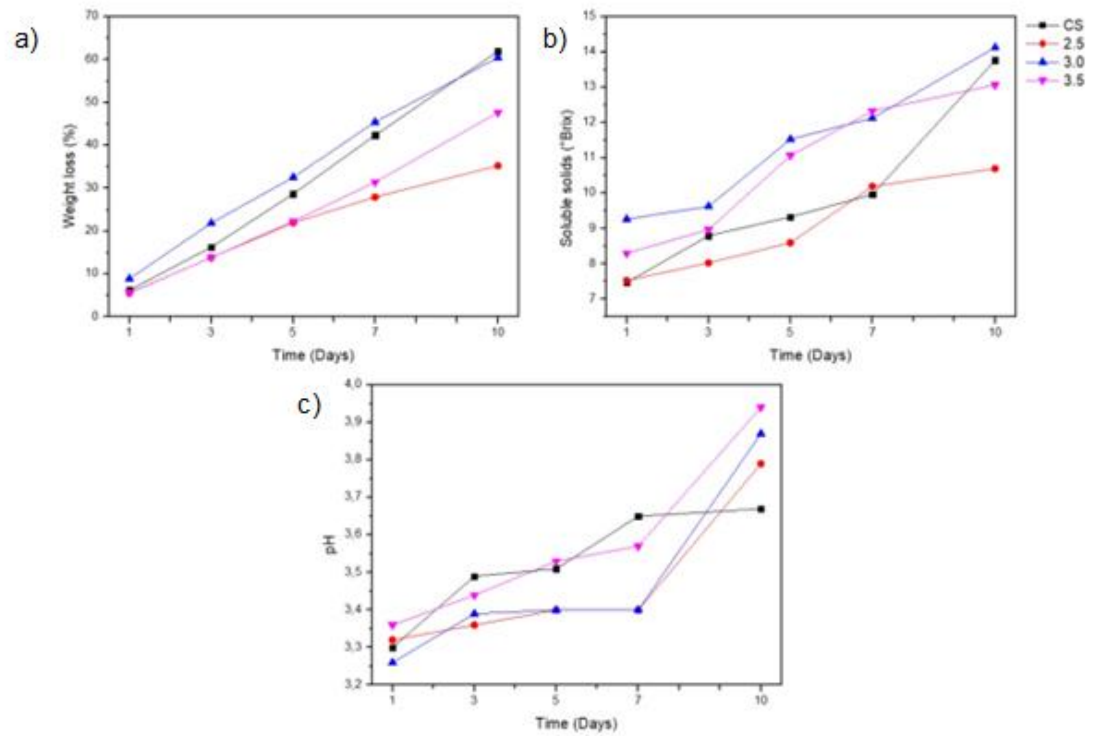

Figure 5. a) Evaluation of weight loss, b) Total Soluble solids (TSS) content and c) pH of strawberries, in a period of 10 days under environmental conditions of 25 ± 5 °C. CS: control strawberry; 2.5, 3.0, 3.5: strawberries coated with a film-forming solution containing soybean oil.

In evaluating strawberry weight loss (figure 5a), a gradual reduction was observed during storage of the CS, 3.0 and 3.5, demonstrating that they do not meet the characteristics of strawberry preservation. Coating 2.5 had a better response than other formulations throughout the storage period. Muley & Singhal (2020) state that weight loss is related to moisture loss and gas exchange, which causes tissue weakening and fruit shrinkage. The hydrophobic coating acts as a barrier and restricts weight loss.

The evaluation of TSS (figure 5b), is related to the fruit's metabolism and the hydrolysis of carbohydrates into sugars (Muley & Singhal, 2020). Formulation 2.5 differed significantly from the others since it maintained values below 11 °Brix and slight variation during the 10 days of evaluation. This observation was assigned to the reducing water, keeping the solids concentration practically constant. Additionally, for the other formulations, there was a more significant loss of water, consequently the concentration of existing solids and presenting a higher value of °Brix, these above 14, as shown in figure 5b. A similar result is reported by Lan et al. (2019).

Strawberry pH (figure 5c), can vary depending on other conditions such as climate, management, and variety, since the same cultivar may have different pH values. The pH value of the CS and coated strawberries during storage at 25±5 ºC for 10 days is shown in figure 3c. We can see that on day 1, the pH ranged from 3.26 to 3.36, with no significant difference in values , and demonstrated that the filmogenic solutions used do not significantly alter the pH values when applied to strawberries. Between days 5 to 10, the coated strawberries increased in pH value. In this way, it can be attributed to the conversion of organic acids into sugars and other senescence products (Riaz et al., 2021), while sample C showed no difference during evaluation in this period, as it is in an advanced deterioration process, as observed in Figure 5b. Similar results were found by Dong, Quyen, & Thuy (2020), who reported that edible coating extends strawberry shelf life and reduces ripening effects.

3.2.3 Strawberry color assessment

The pulp color of control and coated strawberries is shown in Figure 6.

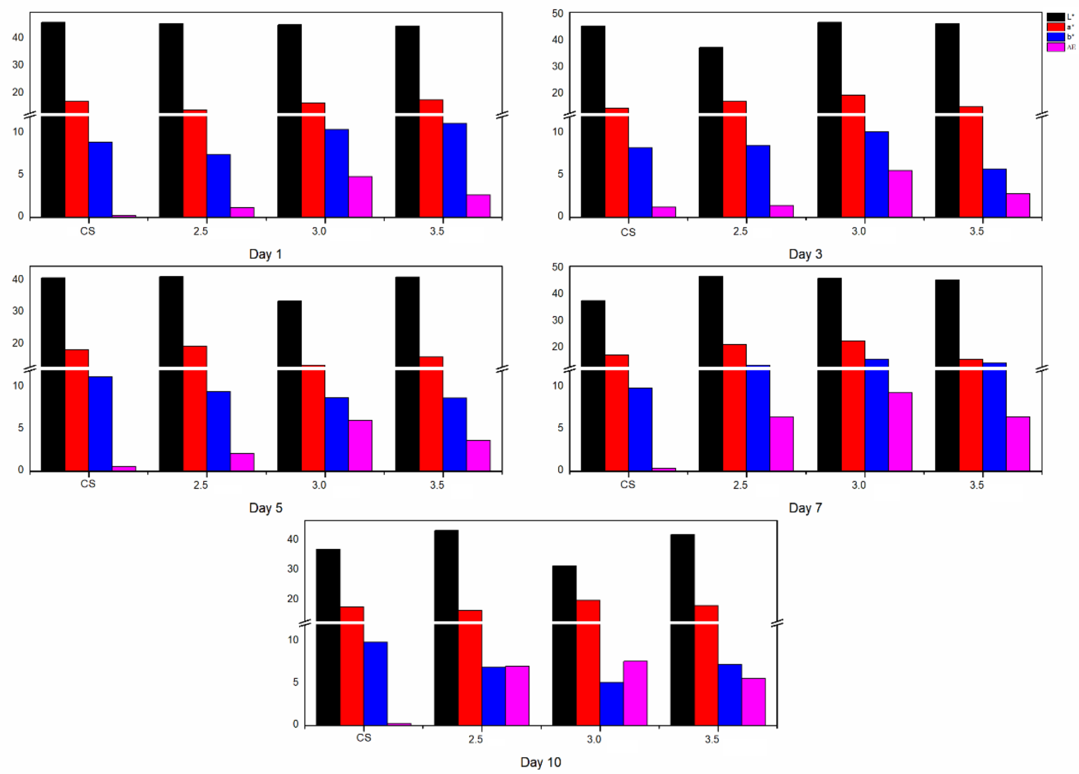

Figure 6. Evaluation of the pulp color of fresh strawberries, in the period of 10 days in ambient conditions of 25±5 °C.

In all parameters, the variation in the color of the pulp of the coated strawberries did not show significant differences concerning CS due to the coating having optical properties of transparency, being pronounced the natural color of the strawberries, as the solution adhered evenly to its surface. The samples' luminosity (L*) varied between 31.50 and 47.25, indicating a tendency toward black color due to the high level of ripening of the strawberries. Positive values for parameters a* and b* indicate the tendency toward red and yellow, respectively, and the increase in values means greater perceptions of these colors. For the color concerning the end of the storage period (10 days), the luminosity parameter (L*) obtained a reduction in relation to the initial time, this may be related to the senescence of strawberries and, consequently, the increase in the values of the parameters a* (redness) and ΔE and reduction of the parameter b* (yellowing).

Other factors that may contribute to the increase in redness of strawberries were the concentration of their TSS concentration, and the stability of their pigments (anthocyanins) caused by the weight loss (water). Sample CS was the most impacted in relation to these factors, in addition to the deterioration process being more advanced. Thus, the values found are similar to those described by Lee et al. (2022), where the coatings reduced moisture loss and cell wall deformation, minimizing the surface color change in post-harvest strawberries.

4. Conclusion

The formulations with the addition of soybean oil demonstrated efficiency in the face of the characteristics evaluated in the films by this casting method. Lager conservation was proportionate to the strawberries, given the influence of the hydrophobic characteristics applied in the solutions filmogenic. Soybean oil emulsifies in the film network, decreasing the availability of free hydroxyls in hydrogen bonds. The water content of strawberries is linked to their high perishability, consequently implying high values of mass loss in uncoated strawberries, a factor that is essential for the functionality of the coating on the surface of the strawberries. It was possible to obtain a longer shelf life, from 3 days (SC) to 10 days (2.5) under storage at 25±5 ºC. The application of formulation 2.5 reached the maintenance of quality, caused a slowdown in metabolism and physiological deterioration of the strawberries, indicating to be a promising alternative to reduce their perishability, and reduce economic losses. Overall, the application of coatings proved to be innovative to prolong the shelf life of strawberries to 10 days, reducing their perishability, and physiological deterioration, and keeping their physical properties unchanged.

Declaration of Competing Interest

No potential conflict of interest was reported by the authors.

CRediT authorship contribution statement

Jéssica Souza Alves Friedrichsen: Conceptualization; Investigation; Formal analysis; Writing - original draft. **Andressa Rafaella Silva Bruni**: Conceptualization; Investigation. **Eloize Silva Alves**: Data curation; Writing - original draft/review/editing. **Bruno Henrique Figueiredo Saqueti:** Investigation; Writing - original draft. **Alisson Lima Figueiredo**: Investigation. **Paulo Ricardo Souza**: Formal analysis; Writing - review & editing. **Jane Martha Graton Mikcha:** Conceptualization; Investigation. **Elton Guntendorfer Bonafé**: Resources; Supervision. **Oscar Oliveira Santos**: Resources; Supervision; Project administration; Roles/Writing - original draft.

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Supplementary material

Edible coatings based on cassava starch incorporating soybean oil: potential application for prolonging the shelf life of strawberries (*Fragaria ananassa*) cv San Andreas

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Table S1 Formulations used in the preparation of the films and coatings.

Fig. S1. Production scheme of solutions filmogenic and application.

Fig. S2. Appearance of films.

Fig. S3. FTIR spectra of solutions filmogenic components.

Fig. S4. Evaluation of the pulp color of fresh strawberries, in the period of 10 days in ambient conditions of 25±5 °C.

Table S1 Formulations used in the preparation of the films and coatings.

Formulations[c]	Distilled water[a] (%)	Cassava starch[b] (%)	Soybean oil (%)	Soy lecithin (%)	Glycerin (%)	PVOH (%)
2.5	95.6	2.5	0.10	0.30	0.75	0.75
3.0	94.9	3.0	0.15	0.45	0.75	0.75
3.5	94.2	3.5	0.20	0.60	0.75	0.75
2.5C	95.5	2.5	-	0.30	0.75	0.75
3.0C	97.7	3.0	-	0.45	0.75	0.75
3.5C	94.0	3.5	-	0.60	0.75	0.75

a: volume of the solutions filmogenic (Petri dish D=150mm)

b: 2.5, 3.0, 3.5 considering the starch's purity degree.

c: 2.5, 3.0, 3.5: formulations with the addition of soybean oil; 2.5C, 3.0C, 3.5C: formulations without the addition of soybean oil.

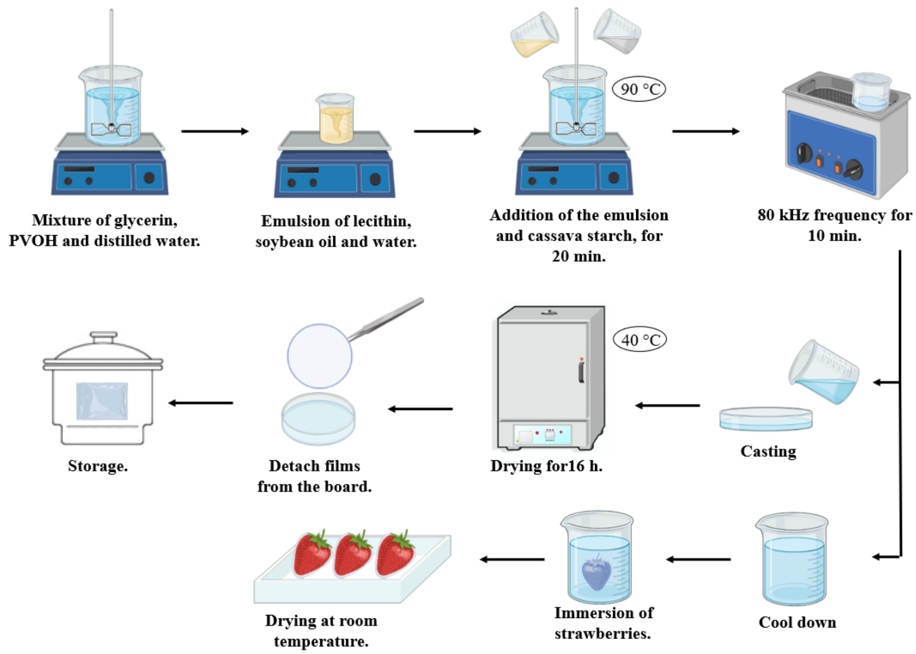

Fig. S1. Production scheme of solutions filmogenic and application.

Fig. S2. Appearance of films. 2.5, 3.0, 3.5: formulations with the addition of soybean oil; 2.5C, 3.0C, 3.5C: formulations without the addition of soybean oil.

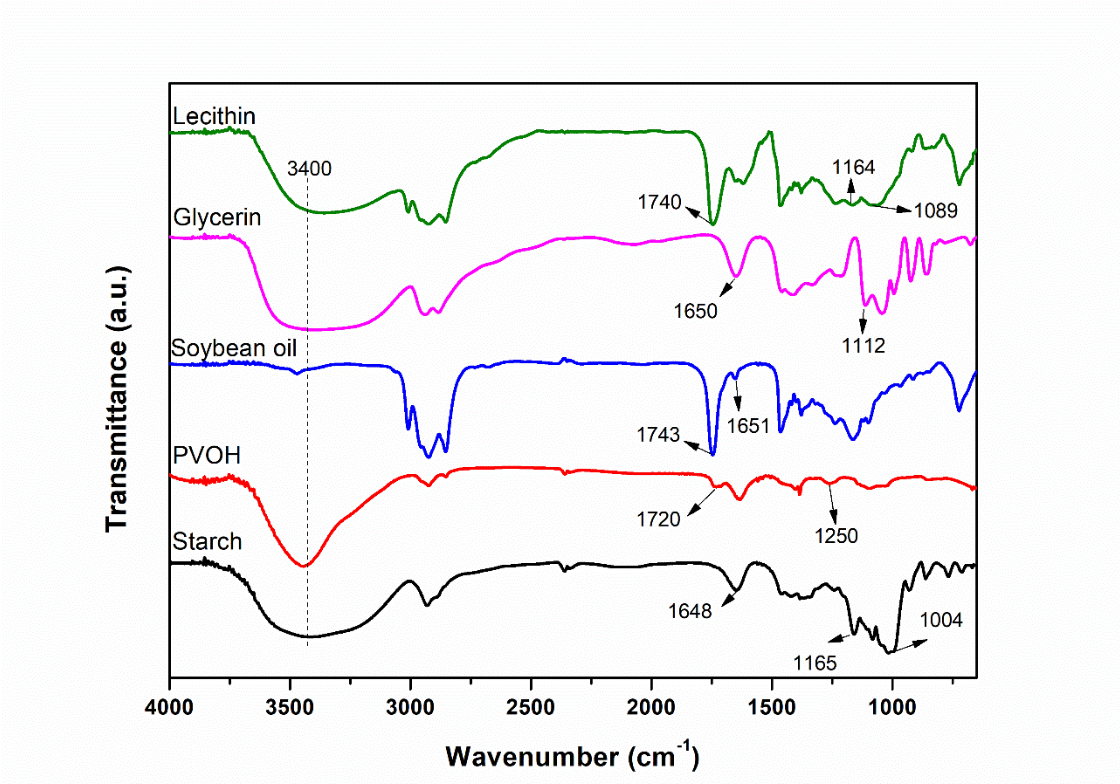

Fig. S3. FTIR spectra of solutions filmogenic components.

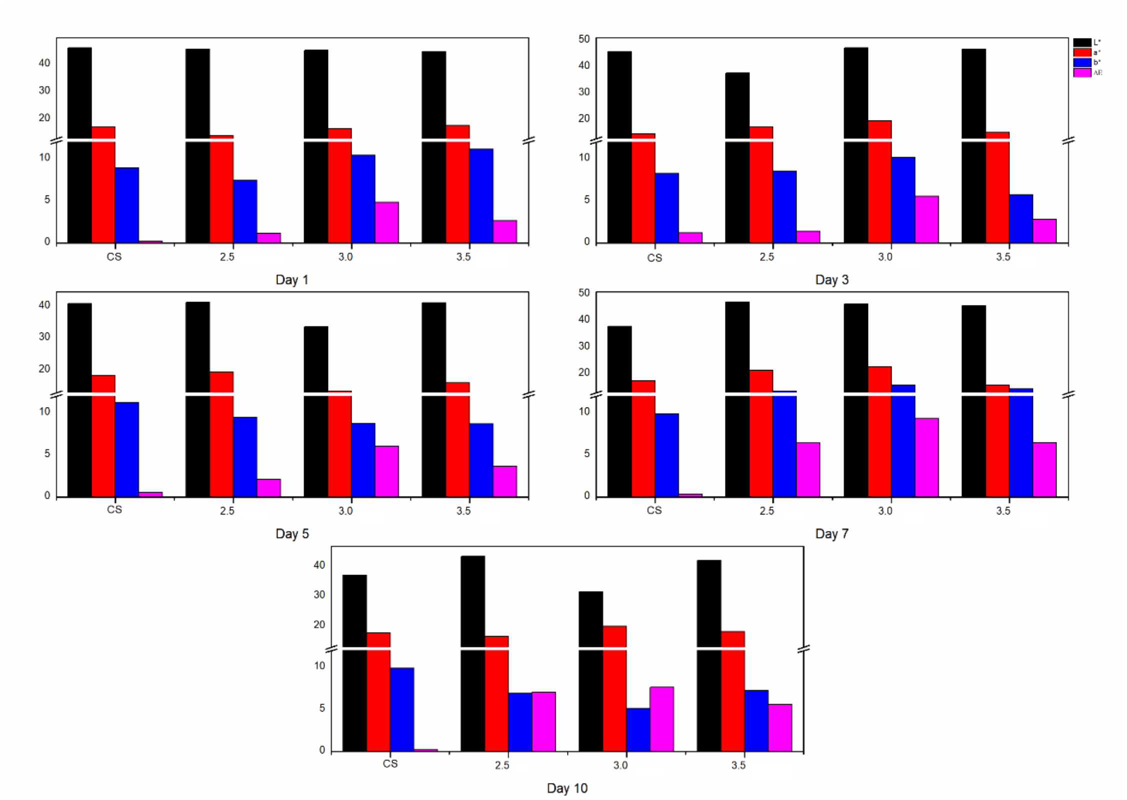

Fig. S4. Evaluation of the pulp color of fresh strawberries, in the period of 10 days in ambient conditions of 25±5 °C.