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Research Article

Formulation Of a Transdermal Patch Containing Pigeon Pea (*Cajanus cajan* L.) Extract As An Antioxidant Agent

Mayang Chairunnisa[1,*], Abdul Rahim[2*], Muh. Taufiqurrahman[3*]

[1,2]Study Program of Pharmacy, Universitas Mulawarman, Samarinda, Indonesia
[3]Study Program of Pharmacy, STIKES Dirgahayu, Samarinda, Indonesia
*Correspondence email : mayangchairunnisa441@gmail.com

Abstract (in English)

Pigeon pea (*Cajanus cajan* L.) is an indigenous Indonesian plant known not only as a food source but also for its high antioxidant content. This study aimed to develop a transdermal patch containing *C. cajan* extract and evaluate its physical properties and antioxidant activity. The extract was obtained through maceration using 96% ethanol and incorporated into patch formulations with varying concentrations of HPMC (10–20%) and PVP (10–20%). The optimal physical characteristics were observed in the formulation containing 20% HPMC and 10% PVP (F1). This base was then combined with the extract at concentrations of 10%, 15%, and 20%, followed by antioxidant testing using the DPPH method. Results showed increased antioxidant activity with higher extract concentrations, with IC_{50} values of F1: 160.87 ppm (weak), F2: 137.09 ppm (moderate), and F3: 96.17 ppm (strong). Formula 3 demonstrated the best performance, combining good physical properties with strong antioxidant activity.

Keywords: pigeon pea, transdermal patch, antioxidant

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1 Introduction

Free radicals are atoms or molecules characterized by unpaired electrons, making them highly reactive and capable of damaging cellular components such as proteins, DNA, and lipids. Accumulating free radicals in the body has been recognized as a contributing factor in various pathological conditions, including premature aging, cancer, and other degenerative diseases. These radicals may originate from normal metabolic processes or external factors such as air pollution, cigarette smoke, and ultraviolet radiation. This issue is of particular concern in Indonesia, where the prevalence of premature aging and oxidative stress-related diseases continues to rise [1].

Antioxidants are compounds that can neutralize free radicals and protect cells from oxidative damage. Although the human body possesses a natural antioxidant defense system, external sources of antioxidants are still required to maintain the balance between oxidants and antioxidants. As public health increasingly looks to concern itself with the undesirable side effects of man-made chemicals, there is a growing demand for antioxidants derived from natural foods, spices, and medicinal plants. Natural antioxidants are more benign and possibly offer additional benefits to health [1].

Pigeon pea (*Cajanus cajan* L.), a member of the Fabaceae family of plants, contains bioactive compounds such as phenolics, flavonoids, and anthocyanins. Various studies have proven the high antioxidant and antibacterial activities of pigeon pea extracts. This characteristic renders *pigeon pea* a candidate natural source of antioxidants for the development of pharmaceutical or cosmetic products [2].

Nowadays, antioxidants in topical products are largely in the form of creams or gels. They possess some disadvantages, for example, instability of active ingredients, low transdermal permeation, and irritation and allergic reactions. Transdermal patches have proved to be a good alternative because they allow a controlled release of the active ingredients, improved skin permeation, and more convenience and comfort to the patient [3], [4].

Based on this background, the present research aims to formulate and evaluate a transdermal patch of pigeon pea extract. Evaluation examines the physical characteristics of the patch and antioxidant activity by the DPPH method. The results will yield a more convenient and effective delivery form of natural antioxidants for the enhancement of skin health and prevention of free radical-coupled damage.

2 Method

2.1 Preparation of Pigeon Pea Extract

Pigeon pea samples (*Cajanus cajan* L.) were cleaned, weighed, and then oven-dried at 60°C for 24 hours. The dried samples were ground and sieved to obtain a simplicia powder. The extraction was performed using the maceration technique using ethanol as the solvent in a glass container with occasional stirring. This was followed by re-maceration until the process was complete. The resulting macerate was filtered and concentrated using a rotary evaporator at 58°C to obtain a thick extract, which was then further dried using a water bath at 60°C and subsequently weighed.

Doi:10.30872/jtpc.v9i1.286

2.2 Formula Design

Table 1 Transdermal Patch Base Optimization Design

Material	Formulation			Standard Of Use	Function
	F1	F2	F3		
HPMC	20%	15 %	10 %	2-20%	Polymer
PVP	10 %	15 %	20 %	5-25%	Polymer
Propylene glycol	10 %	10 %	10%	1-10%	*Enhancer*
PEG 400	10%	10%	10%	5-30%	*Plasticizer*
Aquadest	Ad 100	Ad 100	Ad 100	Ad	Solvent

Table 2 Design of Transdermal Patch Formulation of Gude Bean Extract

Material	Formulation			Standard Of Use	Function
	F1	F2	F3		
Pigeon Pea Extract (*Cajanus cajan* L.)	10%	15%	20%	-	Active Substance
HPMC	X	X	X	2-20%	Polymer
PVP	X	X	X	5-25%	Polymer
Propylene glycol	10 %	10 %	10%	1-10%	*Enhancer*
PEG 400	10%	10%	10%	5-30%	*Plasticizer*
Aquadest	Add 100	Add 100	Add 100	Add	Solvent

2.3 Optimization of Transdermal Patch Base

The patch base optimization was carried out by weighing each ingredient according to the predetermined formulation. HPMC was first dissolved in hot water, followed by the addition of PVP, which had been previously dissolved separately in hot water. The two solutions were stirred together until a homogeneous mixture was obtained. Propylene glycol and PEG 400 were then added to the mixture, followed by the addition of distilled water to reach a final volume of 10 mL. The mixture was left to stand for a while to allow any bubbles to dissipate. Approximately 3 grams of the mixture were poured into a 66 mm diameter petri dish and dried in an oven at 40°C for approximately 6 hours. After drying, the film was placed in a desiccator for 24 hours. The resulting patch was then removed from the mold and cut into 3 x 3 cm pieces. Physical evaluations were conducted, including organoleptic examination, pH measurement, weight uniformity, thickness, and moisture absorption capacity. The base formulation that exhibited the best physical characteristics was subsequently used for preparing the patch containing pigeon pea extract.

2.4 Preparation of Transdermal Patch Containing Pigeon Pea (*Cajanus cajan* L.) Extract

The transdermal patch containing pigeon pea (*Cajanus cajan* L.) extract was prepared by weighing all ingredients according to the designated formula. HPMC was dissolved in hot water, followed by the addition of PVP that had been previously dissolved in hot water, while stirring continuously. The pigeon pea extract was dispersed separately in a mortar using a sufficient amount of distilled water, then added to the HPMC-PVP mixture and stirred until homogeneous. Propylene glycol and PEG 400 were added, followed by the addition of distilled water to a final volume of 10 mL. The mixture was allowed to stand momentarily to eliminate bubbles. About 3 grams of the resulting formulation were cast into a 66 mm

Doi:10.30872/jtpc.v9i1.286

diameter petri dish and dried in an oven at 40°C for approximately 6 hours. After drying, the film was stored in a desiccator for around 24 hours. The dried film was removed from the mold and cut into 3 x 3 cm pieces.

2.5 Evaluation of the Transdermal Patch Containing Pigeon Pea (*Cajanus cajan* L.) Extract

2.5.1 Organoleptic Test

This test involves visual and sensory observation of the patch's shape, color, odor, texture, and surface condition.

2.5.2 pH Test

The pH was measured by placing a pH meter directly on the surface of the patch and allowing the device to stabilize before recording the reading. The mean and standard deviation were then calculated. A pH range of 5.0 to 6.5 is considered safe for topical application.

2.5.3 Weight Uniformity Test

This test was carried out by weighing three patches from each formulation and calculating the average weight. The patch is considered to have uniform weight if it falls within the range of 0.20–0.22 grams.

2.5.4 Thickness Test

Patch thickness was measured using a micrometer screw or caliper at three different points. To meet the specification, the patch thickness should not exceed 1 mm.

2.5.5 Moisture Absorption Capacity Test

The patches were stored at room temperature in a desiccator for 24 hours, then weighed. After that, they were exposed to a temperature of 40°C for another 24 hours and weighed again. An acceptable moisture content for transdermal patches is less than 10%.

2.5.6 Hedonic Test

This assessment measures the level of user preference based on the patch's color, texture, and aroma. It was conducted with 30 untrained panelists aged 18 and above, all female, and in good health without sensory impairments. The hedonic test used a 5-point scale: 1 = strongly like, 2 = like, 3 = neutral or moderately like, 4 = dislike, and 5 = strongly dislike.

2.6 Antioxidant Activity Testing of the Transdermal Patch Containing Pigeon Pea (*Cajanus cajan* L.) Extract

The antioxidant activity was evaluated using the DPPH (2,2-diphenyl-1-picrylhydrazyl) assay method. A 40 ppm DPPH solution was prepared by dissolving 3.9432 mg of DPPH in methanol up to a final volume of 100 mL. The maximum absorbance wavelength was determined at 516 nm using a UV-Vis spectrophotometer. Test solutions of *Cajanus cajan* extract and the formulated patch were prepared at an initial concentration of 100 ppm and further diluted to a series of concentrations ranging from 20 to 100 ppm using methanol. Positive control (ascorbic acid) and negative control (patch base without extract) solutions were also prepared at the same concentration range. For each sample, 1 mL of the test solution was mixed with 1 mL of 40 ppm DPPH solution and 3 mL of methanol. The mixture was incubated in the dark for 30 minutes, after which absorbance was measured at 516 nm to determine antioxidant activity.

3 Result and Discussion

3.1 Pacth Base Optimization Result

Physical evaluation of the patch was conducted to identify the optimal formulation. The parameters assessed included organoleptic characteristics, pH, weight uniformity, thickness, and moisture absorption capacity [5].

Doi:10.30872/jtpc.v9i1.286

Table 3. Organoleptic Evaluation Results of Patch Base

Test Parameters	Formulation			Standard Parameters
	F1	F2	F3	
Shape	Thin, forming a film	Thin, forming a film	Thicker, forms a film	Thin, forming a film
Color	Colorless, transparent	Colorless, transparent	Colorless, transparent	Colorless, transparent
Aroma	Distinctive base aroma	Distinctive base aroma	Distinctive base aroma	Distinctive base aroma
Texture	Dry, smooth, even, elastic, slightly sticky	Slightly wet, smooth, even, elastic, sticky	Wet, smooth, even, elastic, very sticky	Dry, smooth, even, elastic, slightly sticky
Picture				-

The organoleptic assessment examined the color, shape, odor, texture, and surface condition of the patches. Formula F1 was considered the most optimal, as it produced a dry, smooth, flat, elastic, and non-sticky patch. This can be attributed to the high concentration of HPMC, which does not cause wrinkling [6]. In contrast, Formula F3 exhibited a wetter and highly sticky surface, likely due to the high concentration of PVP, which has hygroscopic properties [7], [3] Nevertheless, PVP also offers benefits in enhancing adhesiveness and elasticity.

Table 4 Results of Patch Base pH Test

Replication of Stock	pH Test			Standard Parameters
	F1	F2	F3	
1	6,44	6,50	5,53	4,5 - 6,5
2	6,44	6,41	5,50	
3	6,50	6,53	5,50	
Average±SD	6,46±0,0346	6,48±0,062	5,51±0,017	

The pH test showed that all formulations remained within the skin's physiological pH range (4.5–6.5). HPMC contributed to a higher pH due to its hydroxyl groups, which can release OH^- ions, while PVP tended to lower the pH because its carbonyl groups release H^+ ions [8].

Table 5 Results of Patch Base Weight Uniformity Test

Replication of Stock	Weight (g)			Standard Parameters
	F1	F2	F3	
1	0,61	0,65	0,67	0,6 - 0,67
2	0,62	0,62	0,69	
3	0,60	0,63	0,65	

Doi:10.30872/jtpc.v9i1.286

Average±SD	0,61±0,010	0,63±0,015	0,67±0,020	
Coefficient of Variation (%)	0,006	0,004	0,003	≤5%

The weight uniformity test indicated that Formulas F1 and F2 met the standard requirements, while one replicate of F3 did not comply. This inconsistency is presumed to be due to oven conditions and inaccuracies during the weighing process. The higher weight observed in F3 is likely associated with the hygroscopic nature of PVP [9].

Table 6 Patch Base Thickness Test Results

Replication of Stock	Average Thickness at 3 Points (mm)			Standard Parameters
	F1	F2	F3	
1	0,27	0,40	0,30	≤1 mm
2	0,30	0,43	0,50	
3	0,27	0,33	0,57	
Average±SD	0,28±0,017	0,38±0,051	0,45±0,140	

Three measurements were taken for thickness. Formula F1 had the best result with the lowest thickness and meeting standard standards. Formula F3 had greater thickness, likely due to its greater PVP concentration. In addition, technical issues such as mixing method and drying conditions were also a contributing factor to the result [10].

Table 7 Moisture Absorption Test Results of Patch Base

Replication of Stock	Moistute Absorption Capacity (%)			Standard Parameters
	F1	F2	F3	
1	0,34	0,32	0,36	≤10%
2	0,32	0,37	0,36	
3	0,36	0,36	0,35	
Average±SD	0,34±0,020	0,35±0,026	0,36±0,005	

Moisture uptake test was carried out to check residual moisture content in the patches. The required limit of <10% for all formulas was achieved; however, Formula F1 contained minimum moisture content, indicating best stability. Conversely, higher moisture content in Formula F3 may elevate risk of microbial contamination, as PVP is a hygroscopic substance [11], [9].

Following all the evaluation criteria, Formula F1 (20% HPMC and 10% PVP) was the best performing. This formula met all the requirements and formed a thin, dry, and non-sticky patch that was more stable. Formulas F2 and F3, though they still met most of the requirements, exhibited higher moisture and thickness, which may hinder the release of active components and might cause contamination.

3.2 Physical Evaluation Results of the Transdermal Patch Formulation

Pigeon pea extract was selected as the active component due to its bioactive compounds of flavonoids and alkaloids that are well-documented as antioxidant agents and UV protectants [12]. Patch formulations were then prepared at various extract concentrations of 10%, 15%, and 20% in order to evaluate the effect of active ingredient concentrations on physical stability, pharmacological activity, and skin safety. Patch formulations. This approach is in compliance with previous studies showing that higher

Doi:10.30872/jtpc.v9i1.286

concentrations will enhance antioxidant and antibacterial activity [3], [13]. The patches were fabricated using HPMC, PVP, propylene glycol, and PEG 400, and evaluated by organoleptic examination, pH, weight uniformity, thickness, moisture absorption, and hedonic test.

Table 8 Organoleptic Test Results of Transdermal Patch Preparations

Test Parameters	Formulation			
	F0	F1	F2	F3
Shapes	Thin, forming a film	Thin, forming a film	Thin, forming a film	Thin, forming a film
Color	Colorless, transparent	Bright yellow, transparent	Slightly dark yellow, transparent	Slightly dark yellow, transparent
Aroma	Distinctive base aroma	The distinctive aroma of pigeon peas	The distinctive aroma of pigeon peas	The distinctive aroma of pigeon peas
Texture	Dry, smooth, even, elastic, slightly sticky	Dry, smooth, even, elastic, slightly sticky	Dry, smooth, even, elastic, slightly sticky	Dry, smooth, even, elastic, slightly sticky
Picture				

Formulations with varying extract concentrations displayed differences in physical characteristics. The control formulation (F0), which contained no extract, was transparent, colorless, had a typical base aroma, and exhibited a thin, smooth, and elastic texture. Formulations F1 through F3 showed similar physical traits but were accompanied by the distinct aroma of pigeon pea and progressively deeper coloration corresponding to the increasing concentration of extract.

Table 9 Results of pH Test of Transdermal Patch Preparations

Replication of Stock	pH Test				Standard Parameters
	F0	F1	F2	F3	
1	6,41	4,54	4,54	4,46	4,5 - 6,5
2	6,50	4,56	4,54	4,42	
3	6,53	4,56	4,50	4,46	
Average±SD	6,48±0,0062	4,55±0,011	4,52±0,023	4,44±0,023	

The pH evaluation showed that the control formulation (F0) had an average pH of 6.48 ± 0.062, while F1, F2, and F3 had values of 4.55 ± 0.011, 4.52 ± 0.023, and 4.44 ± 0.023, respectively. The decreasing trend in pH aligns with the mildly acidic nature of pigeon pea extract, which contains phenolic acids, phytic acid, flavonoids, and amino acids [14]. Formulations F0 to F2 fell within the ideal pH range for topical preparations (4.5–6.5), although F3 slightly dropped below the lower limit [15].

Table 10 Results of Transdermal Patch Preparation Weight Uniformity Test

Doi:10.30872/jtpc.v9i1.286

Replication of Stock	Weight (g)				Standard Parameters
	F0	F1	F2	F3	
1	0,61	0,60	0,60	0,66	0,6 - 0,67
2	0,62	0,61	0,62	0,65	
3	0,60	0,67	0,67	0,63	
Average±SD	0,61±0,010	0,62±0,037	0,63±0,036	0,64±0,015	
Coefficient of Variation (%)	0,006	0,001	0,001	0,004	≤5%

In the weight uniformity test, all four formulations showed less than 5% variation, indicating good uniformity [6]. The average weights of formulations F0 to F3 were 0.61, 0.62, 0.63, and 0.64 grams, respectively. Weight gain conformed to the rise in the concentration of the extract, resulting from the hydrophilic nature of pigeon pea extract that has the property of absorbing water. Technical reasons such as accuracy in weighing and temperature fluctuations during drying may also have influenced weight variations [11], [16].

Table 11 Results of Transdermal Patch Preparation Thickness Test

Replication of Stock	Average Thickness at 3 Points (mm)				Standard Parameters
	F0	F1	F2	F3	
1	0,27	0,30	0,27	0,33	≤1 mm
2	0,30	0,23	0,43	0,27	
3	0,27	0,23	0,20	0,33	
Average±SD	0,28±0,017	0,25±0,040	0,38±0,051	0,31±0,034	

Thickness was measured at three places for each formula. Mean thickness for F0 to F3 samples was 0.28 mm, 0.25 mm, 0.30 mm, and 0.31 mm, respectively. Increase in thickness was consistent with higher extract content due to possibly the hydrophilic nature of the extract since it enhances water retention and increases film thickness [11], [17]. Factors such as imperfections of the casting surface or uneven temperature distribution during drying can also be accountable for such differences. All preparations were within the optimal maximum thickness of 1 mm [6].

Table 12 Moisture Absorption Test Results of Transdermal Patch Preparations

Replication of Stock	Moistute Absorption Capacity (%)				Standard Parameters
	F0	F1	F2	F3	
1	0,34	0,36	0,38	0,36	≤10%
2	0,32	0,34	0,35	0,38	
3	0,36	0,34	0,35	0,38	
Average±SD	0,34±0,020	0,34±0,011	0,36±0,017	0,37±0,011	

The percentage of moisture absorption increased in line with higher extract concentrations, with average values of 0.34%, 0.34%, 0.36%, and 0.37% for F0 through F3, respectively. The hydrophilic properties of the extract contributed to the patch's enhanced ability to absorb moisture from the surrounding environment [11]. All formulations met the maximum allowable moisture absorption limit of 10% [9].

Table 13 Hedonic Test Results of Transdermal Patch Preparations

Doi:10.30872/jtpc.v9i1.286

Test Parameters	Average Likeability Score				Standard Parameters
	F0	F1	F2	F3	
Color	2,06	2,03	2,30	3,03	Score 1 = Like it very much Score 2 = Like Score 3 = Quite like it Score 4 = Dislike Score 5 = Dislike very much
Texture	2,30	2,20	2,20	2,40	
Aroma	2,40	2,56	3,03	3,06	
Overall	2,25	2,26	2,50	2,83	

The hedonic test was conducted on parameters of color, texture, and aroma using 30 untrained panelists at the Tropical Pharmaca Laboratory, Mulawarman University. The average color scores for formulations F0 through F3 were 2.06, 2.03, 2.30, and 3.03, respectively, indicating a progressively darker shade as extract concentration increased [5]. Texture scores ranged from 2.20 to 2.40, reflecting consistent panelist preference across all formulations, likely due to the elastic film-forming properties of the HPMC and PVP combination. Aroma scores rose from 2.40 (F0) to 3.06 (F3), corresponding with the intensified characteristic scent of *Cajanus cajan*. Overall hedonic scores for F0 to F3 were 2.25, 2.25, 2.50, and 2.83, respectively, suggesting favorable acceptance of the *Cajanus cajan* transdermal patch formulations by the panelists.

3.3 Antioxidant Activity Test Results

Table 14 Antioxidant Activity Test Results

Sample		Concentration (ppm)	Ln Concentration	Absorbance	%Inhibition	Regression Equation	IC_{50}
Pigeon Pea Extract (*Cajanus cajan* L.)	10 %	20	2,995732274	0,723	8,248730964	y= 26,465x - 74,19 R^2= 0,9374	109,137 ppm (Moderate)
		40	3,688879454	0,653	17,1319797		
		60	4,094344562	0,525	33,37563452		
		80	4,382026635	0,42	46,70050761		
		100	4,605170186	0,42	46,70050761		
	15 %	20	2,995732274	0,629	20,17766497	y= 21,48x - 44,433 $R^{2=}$ 0,9672	81,151 ppm (Strong)
		40	3,688879454	0,517	34,39086294		
		60	4,094344562	0,432	45,17766497		
		80	4,382026635	0,428	45,68527919		
		100	4,605170186	0,339	56,97969543		
	20 %	20	2,995732274	0,618	21,57360406	y= 27,991x - 65,58	62,127 ppm (Strong)
		40	3,688879454	0,521	33,88324873		

Doi:10.30872/jtpc.v9i1.286

		60	4,094344562	0,427	45,81218274	R^2= 0,9568	
		80	4,382026635	0,345	56,21827411		
		100	4,605170186	0,253	67,89340102		
Pigeon Pea Extract Patch Preparation	F1	20	2,995732274	0,223	9,349593496	y=21,994x - 61,743 R^2= 0,834	160,872 ppm (Weak)
		40	3,688879454	0,223	9,349593496		
		60	4,094344562	0,178	27,64227642		
		80	4,382026635	0,148	39,83739837		
		100	4,605170186	0,148	39,83739837		
	F2	20	2,995732274	0,225	8,536585366	y= 24,492x - 70,561 R^2= 0,7329	137,088 ppm (Moderate)
		40	3,688879454	0,208	15,44715447		
		60	4,094344562	0,208	15,44715447		
		80	4,382026635	0,133	45,93495935		
		100	4,605170186	0,133	45,93495935		
	F3	20	2,995732274	0,221	10,16260163	y= 30,906x - 91,12 R^2= 0,8059	96,168 ppm (Strong)
		40	3,688879454	0,221	10,16260163		
		60	4,094344562	0,178	27,64227642		
		80	4,382026635	0,119	51,62601626		
		100	4,605170186	0,109	55,69105691		
Ascorbic Acid		20	2,995732274	0,325	58,75634518	y= 8,5315x + 20,826 R^2= 0,9378	10,307 ppm (Very Strong)
		40	3,688879454	0,314	60,15228426		
		60	4,094344562	0,314	60,15228426		
		80	4,382026635	0,223	71,70050761		
		100	4,605170186	0,212	73,09644677		
Patch Base		20	2,995732274	0,231	18,11414392		7928,571 ppm

Doi:10.30872/jtpc.v9i1.286

40	3,688879454	0,23	18,46862815	y= 5,6541x - 0,7638 R^2= 0,6685	(Have no Activity)
60	4,094344562	0,229	18,82311237		
80	4,382026635	0,212	24,8493442		
100	4,605170186	0,204	27,68521801		

The DPPH method was selected due to its rapid, simple, and sensitive measurement of antioxidant activity, even in small sample volumes [18]. Absorbance was measured using a UV-Vis spectrophotometer at 516 nm to calculate inhibition values and IC_{50}. Based on classification, IC_{50} values <50 ppm indicate very strong activity, 50–100 ppm strong, 100–150 ppm moderate, and >200 ppm very weak [19]. The concentration range of 20–100 ppm was used to ensure linearity and sensitivity, as absorbance values fell within the ideal range of 0.2–0.8 for UV-Vis measurements [20], [21].

The antioxidant test results for *Cajanus cajan* extract showed IC_{50} values of 109.137 ppm (moderate activity) at 10%, 81.151 ppm (strong) at 15%, and 62.127 ppm (strong) at 20%. These results align with the known antioxidant compounds in *Cajanus cajan*, such as flavonoids, polyphenols, and cyanidin-3-monoglucoside, which play key roles in neutralizing free radicals [12], [2]. Thus, *Cajanus cajan* extract demonstrates significant antioxidant potential against oxidative stress.

In the transdermal patch formulations, antioxidant activity varied with extract concentration. F1 (10%) showed weak activity (IC_{50} = 160.872 ppm), F2 (15%) was moderate (IC_{50} = 137.088 ppm), and F3 (20%) was strong (IC_{50} = 96.168 ppm), while the negative control (F0) showed no activity (IC_{50} = 7928.571 ppm). Ascorbic acid, used as a positive control, exhibited very strong activity (IC_{50} = 10.307 ppm). Although activity decreased in the patch formulations compared to pure extracts—likely due to the influence of excipients—the absence of antioxidant activity in the base formulation confirms that the antioxidant effect originated from the extract itself. These findings suggest the patch remains effective, particularly at higher extract concentrations.

4. Conclusion

In the process of optimizing the transdermal patch matrix, formulation F1 demonstrated the most favorable physical attributes, including ideal thickness, moisture content, and homogeneity. All tested formulations (F0–F3) met the fundamental physicochemical criteria for transdermal delivery systems. Nonetheless, the evaluation of antioxidant activity indicated that formulation F2, which incorporates 15% *Cajanus cajan* extract, exhibited the most balanced profile—combining moderate antioxidant efficacy with satisfactory physical stability. Accordingly, formulation F2 is regarded as the most suitable candidate for further development, as it presents an optimal balance between structural performance and therapeutic potential.

5. Declarations

5.1 Acknowledgements (Optional)

All authors contributed to the design, writing, and editing of the manuscript.

5.2 Author contributions

The author declares that there is no conflict of interest in this research

5.4 Conflict of Interest

The author declares that there is no conflict of interest in this research

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