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Applications and Characterisation of Aloe Vera Nanocoating on Arabica Coffee (*Coffea Arabica*) at Varying Concentrations and Soaking Times

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Abstract

Arabica coffee (*Coffea arabica*) is susceptible to quality deterioration during storage, partly due to mold and yeast growth. Aloe vera gel-based coating may serve as a natural preservation alternative because it contains bioactive compounds and can form a protective layer on food surfaces. This study evaluated the effects of Aloe vera gel concentration and dipping time on the physicochemical quality and mold and yeast counts of Arabica coffee beans during 28 days of storage. A factorial completely randomized design was applied, consisting of four coating concentrations (0%, 25%, 50%, and 100%) and three dipping times (1, 2, and 3 min), with three replicates per treatment. Samples were analyzed on days 0, 14, and 28 for moisture content, water activity, color (L*, a*, b*), caffeine, total phenolics, and mold and yeast counts. Data were analyzed by ANOVA followed by DMRT at 5%. Concentration significantly affected moisture content on day 0, water activity on days 0 and 14, and mold and yeast counts on days 14 and 28. Dipping time significantly affected mold and yeast counts on day 28. No significant interaction between concentration and dipping time was observed. The 100% treatment produced the lowest mold and yeast counts on days 14 (2.4×10^2 CFU/g) and 28 (3.6×10^2 CFU/g), while 3-min dipping produced the lowest count on day 28 (3.4×10^2 CFU/g). Neither factor significantly affected color, caffeine, or total phenolic content. These findings indicate that Aloe vera gel-based coating has potential to help control mold and yeast growth without significant changes in selected color and chemical quality parameters.

Keywords: Aloe Vera, Arabica Coffee Beans, Edible Coating, Mold and Yeast, Storage

1. Introduction

Arabica coffee (*Coffea arabica* L.) is a high-value agricultural commodity characterized by its distinctive flavour and aroma. The quality of coffee beans is determined not only by the variety and processing method, but also by storage conditions following harvest. Coffee beans are hygroscopic and can therefore absorb water vapour from the environment. Changes in moisture content and water activity during storage can affect product stability and create conditions that flavour the growth of microorganisms (Anokye-Bempah *et al*., 2023; Błaszkiewicz *et al*., 2023) [2, 3].

Mould contamination in coffee beans is a cause for concern as some fungi can impair physical and sensory quality and have the potential to produce mycotoxins, including ochratoxin A. Fungal growth is influenced by water activity, temperature, relative humidity, the condition of the material, and the duration of storage. Consequently, controlling the growth of moulds and yeasts is a crucial aspect of maintaining the quality and safety of coffee beans during storage (Estrada-Bahena *et al*., 2022; Mannaa & Kim, 2018; Navale *et al*., 2021) [6, 10, 11].

An edible coating is a thin layer applied to the surface of foodstuffs to modify the transfer of gases and water vapour and to provide protection against environmental factors. Coating materials may consist of polysaccharides, proteins, lipids, or a combination of several substances. The effectiveness of the coating is influenced by the composition of the solution, viscosity, thickness, uniformity, and application conditions, including the duration of immersion (Cisneros-Zevallos & Krochta, 2003; Chavan *et al*., 2023; Ali *et al*., 2025) [5, 4, 1].

Aloe vera is a plant-based material that has been extensively studied as a coating agent, as its gel forms a film and contains bioactive compounds with potential antimicrobial and antioxidant activity. A number of studies have reported the use of Aloe vera gel to preserve the quality of fruit and vegetables during storage and to inhibit post-harvest fungi (Nicolau-Lapeña *et al*., 2021; Hasan *et al*., 2021; Sempere-Ferre *et al*., 2022) [12, 7, 14]. The use of ultrasonication in the formulation can aid the

homogenization process and the formation of a more uniform dispersion. However, claims regarding nano-scale particles must be supported by direct particle size measurements.

In coating applications, the immersion time determines the contact time between the solution and the surface of the material. Contact time can affect wetting, deposition and coating uniformity, whilst the concentration of the coating material may influence the physical properties of the solution and its ability to form a coating. The combination of these two factors needs to be evaluated in order to achieve an effective treatment without altering the quality characteristics of the coffee beans.

This study aims to analyses the effect of the concentration of an Aloe vera gel-based coating and the duration of immersion on the moisture content, water activity, colour, caffeine content, total phenols and mould and yeast count of Arabica coffee beans during 28 days' storage. The results of this study are expected to provide preliminary information on the potential use of Aloe vera gel as a natural coating to help maintain the microbiological quality of coffee beans.

2. Materials and Methods

2.1 Research materials and location

The research was carried out from March to June 2026 at the Food Processing Laboratory of Udayana University and the Faculty of Agriculture laboratory at Warmadewa University. The main materials used were fresh Aloe vera leaves aged 8–12 months and wet-processed Arabica green coffee beans. The analytical materials included distilled water (technical grade), 70% ethanol (Smart Lab), NaCl (Oxoid), Potato Dextrose Agar (PDA) medium (Oxoid), Folin–Ciocalteu reagent (Merck), sodium carbonate (Merck), chloroform (Smart Lab), and caffeine standard (Merck). The main equipment included an analytical balance (Ohaus), a blender/homogenizer, an ultrasonicator, an oven (Memmert), a water activity meter, a colorimeter, a UV-Vis spectrophotometer -Vis spectrophotometer (Libra S60), an incubator (Memmert), an autoclave (Hirayama), Petri dishes, micropipettes (Socorex), test tubes (Pyrex), test tube racks, and Erlenmeyer flasks (Pyrex).

2.2 Experimental design

The study employed a two-factor completely randomized design (CRD). The first factor was the concentration of Aloe vera gel (K), namely 0 %(control), 25 %, 50 %, and 100 %. The second factor was the immersion time (C), namely 1, 2 and 3 minutes. Each treatment combination was repeated three times, resulting in 36 experimental units (4 × 3 × 3). Observations were made on days 0, 14 and 28 during storage.

2.3 Preparation of the coating solution and application

Aloe vera leaves were washed, peeled, and the clear gel separated from the skin and yellow latex. The gel was cut, weighed, and then ground until homogeneous. The gel was diluted with distilled water to the treatment concentrations (0%, 25%, 50% and 100%), then homogenized using an ultrasonicator for 30 minutes. The solutions were stored in dark glass bottles at a temperature of approximately 4°C until use. Coffee beans were sorted and cleaned, then immersed in the coating solution for 1, 2, or 3 minutes. The samples were drained and dried at a temperature of approximately 40°C for approximately 2 hours until the coating had dried. The samples were then stored at 28°C and a relative humidity of approximately 70 per cent until the time of observation.

2.4 Coffee Quality Analysis

Moisture content was determined using the oven method at 105°C until a constant weight was reached and is expressed as a percentage. Water activity (aw) was measured using a water activity meter at a controlled measurement temperature. Colour was measured using a colorimeter and expressed as L* (lightness), a* (green–red component) and b* (blue–yellow component). Caffeine content was determined by UV-Vis spectrophotometry at a wavelength of 281 nm following extraction and the preparation of a standard curve. Total phenols were analyzed using the Folin–Ciocalteu method, with absorbance readings taken at 760 nm and compared against a gallic acid standard curve. Mould and yeast counts were calculated using the spread plate method. A 1 g sample was homogenized in a sterile diluent and serially diluted. Aliquots were inoculated onto PDA medium supplemented with antibiotics, then incubated at 25–30°C for 3–5 days. Colonies were counted on plates within the count range and expressed as CFU/g. Surface morphology was observed in selected samples using *Scanning Electron Microscopy* (SEM); the available documentation shows the surface of coffee beans with a layer that appears not to be entirely homogeneous.

2.5 Data Analysis

The data were analyzed using analysis of variance (ANOVA) at a 95 per cent confidence level ($\alpha = 0.05$) to test the effects of concentration, soaking time and the interaction between the two. Where significant effects were found, differences in means were tested using Duncan's Multiple Range Test (DMRT) at the 5 per cent level.

3. Results and Discussion

Moisture Content (%)

Based on Table 2, the moisture content of Arabica coffee beans on day 0 showed differences depending on the concentration of the Aloe vera nanocoating treatment. The highest moisture content was observed at a concentration of 25 %, namely 8.280 %, whilst the lowest moisture content was observed at a concentration of 50 %, namely 7.590 %. The results of the study showed that at the start of the observation period, the application of a 50 % concentration of Aloe vera nanocoating resulted in a lower moisture content in the coffee beans compared with the other concentration treatments. On day 14, the moisture content ranged from 8.776–9.790 %, whilst on day 28 it ranged from 9.857–10.807 %. Although there were variations in moisture content values between concentrations, there were no statistically significant differences between any of the treatments on days 14 and 28. Moisture content tended to increase during storage across all treatments.

Based on the soaking time treatments, the moisture content of the coffee beans on day 0 ranged from 7.877–8.226 %. A 1-minute soak produced the lowest moisture content, at 7.877 %, whilst a 3-minute soak produced the highest, at 8.226 %. On day 14, the moisture content ranged from 9.028–9.574 %, whilst on day 28 it ranged from 9.977–10.439 %. There were no statistically significant differences between the soaking time treatments at either time point. Descriptively, an increase in soaking time from 1 to 3

minutes was followed by an increase in moisture content on days 0 and 14, but this pattern did not continue on day 28. This difference indicates that soaking time is associated with variations in moisture content at the start of the observation period, but did not show significant differences during subsequent storage.

Overall, Table 2 shows that differences in the concentration of the Aloe vera nanocoating and soaking time on the moisture content of coffee beans were primarily detected on day 0, whilst on days 14 and 28, the differences between treatment levels were not significant. The moisture content of all treatments tended to increase during storage, indicating a change in the moisture balance of the coffee beans in response to the storage environment.

Table 2: Moisture content (%) of coffee beans as a function of the concentration of Aloe vera nanocoating and soaking time

Treatment	Moisture Content – Day 0		Moisture Content – Day 14		Moisture Content – Day 28	
Concentration Treatment						
Concentration 0%	8.112	a	8.776	a	9.944	a
Concentration 25%	8.280	a	9.291	a	10.096	a
Concentration 50%	7.590	b	9.206	a	10.807	a
Concentration 100%	8.235	a	9.790	a	9.857	a
Treatment Duration						
Soak for 1 minute	7.877	b	9.028	a	10.113	a
Soak for 2 minutes	8.061	ab	9.195	a	10.439	a
Soak for 3 minutes	8.226	a	9.574	a	9.977	a

Note: The mean values followed by the same letter in the same column are not significantly different according to the 5% DMRT test.

Water Activity (Aw)

Based on Table 3, the water activity (Aw) of Arabica coffee beans on day 0 showed that the treatment with different concentrations of Aloe vera nanocoating produced significant differences. The highest water activity was found at a concentration of 0% (control), namely 0.640, whilst the lowest value was found at a concentration of 25%, namely 0.622. Based on the results of the 5% DMRT test, the 0% concentration differed significantly from the 25%, 50% and 100% concentrations. On day 14, the highest water activity was found at a concentration of 25%, namely 0.637, whilst the lowest value was observed at a concentration of 100%, namely 0.591. The 100% concentration differed significantly from the 0%, 25% and 50% concentrations, whilst the 0% concentration did not differ significantly from the 50% concentration. On day 28, water activity ranged from 0.624 to 0.641, and no statistically significant differences were observed between any of the treatments. These results indicate that the effect of nanocoating concentration on water activity was evident from the start to the middle of the storage period, but was no longer statistically detectable by the end of storage.

Based on the soaking time treatments, the water activity of the coffee beans on day 0 ranged from 0.627 to 0.629, on day 14 from 0.608 to 0.615, and on day 28 from 0.627 to 0.636. At all three observation times, all soaking time treatments showed significant differences based on the 5% DMRT test. On day 0, the highest water activity was found in the 3-minute soaking treatment, at 0.629, whilst the lowest was in the 1-minute soaking treatment, at 0.627. On day 14, the lowest water activity was observed in the 2-minute soaking treatment, at 0.608, whilst the highest was in the 1-minute soaking treatment, at 0.615. Furthermore, on day 28, the highest water activity was observed in the 3-minute soaking treatment, at 0.636, and the lowest in the 1-minute soaking treatment, at 0.627. The differences in the water activity values of the coffee beans were not statistically significant, meaning that variations in soaking time between 1 and 3 minutes did not have a statistically detectable effect on the water activity of the coffee beans during storage.

Table 3: Water activity of coffee beans as a function of coating concentration and soaking time

Treatment	Water Activity – Day 0		Water Activities – Day 14		Water Activities – Day 28	
Treatment Concentration						
Concentration 0%	0.640	a	0.614	b	0.641	a
Concentration 25%	0.622	b	0.637	a	0.633	a
Concentration 50%	0.627	b	0.600	bc	0.629	a
Concentration 100%	0.623	b	0.591	c	0.624	a
Treatment Storage Duration						
Immersion for 1 minute	0.627	a	0.615	a	0.627	a
Immersion for 2 minutes	0.628	a	0.608	a	0.633	a
Immersion for 3 minutes	0.629	a	0.609	a	0.636	a

Note: The mean values followed by the same letter in the same column are not significantly different according to the 5% DMRT test

Colour L

Based on Table 4, the L colour value of Arabica coffee beans in the treatments with different concentrations of Aloe vera nanocoating varied during storage. On day 0, the highest L value was observed at a concentration of 50 %, namely 47.344, whilst the lowest value was observed at a concentration of 25 %, namely 38.046. On day 14, the highest L value was recorded at a concentration of 100 %, namely 55.726, whilst the lowest value was observed at a concentration of 25 %, namely 47.034. Furthermore, on day 28, the highest L value was observed at a concentration of 50 %, namely 51.370, whilst the lowest value was observed at a concentration of 100 %, namely 45.639. The results of the study indicate that there were no statistically significant differences between the various concentration treatments. This indicates that the concentration of the Aloe vera nanocoating had no significant effect on the L colour value during storage. Consequently, variations in the nanocoating concentration did not result in statistically significant changes in the brightness of the coffee beans.

Table 4: L- colour of coffee beans as a function of the concentration of Aloe vera nanocoating and soaking time

Treatment	Colour L– Day 0		Colour L– Day 14		Colour L– Day 28	
Concentration Treatments						
0% concentration	39.739	a	51.069	a	47.779	a
25% concentration	38.046	a	47.034	a	50.963	a
50% concentration	47.344	a	49.633	a	51.370	a
100% concentration	45.970	a	55.726	a	45.639	a
Storage Duration Treatments						
1-minute immersion	42.255	a	54.259	a	48.745	a
2-minute immersion	41.984	a	50.401	a	48.354	a
3-minute immersion	44.086	a	47.937	a	49.715	a

Note: The mean values followed by the same letter in the same column are not significantly different according to the 5% DMRT test.

Based on the soaking time treatments, the L colour values of the coffee beans on day 0 ranged from 41.984 to 44.086. The highest value was obtained in the 3-minute soaking treatment, namely 44.086, whilst the lowest value was found in the 2-minute soaking treatment, namely 41.984. On day 14, the highest L value was found in the 1-minute soaking treatment, namely 54.259, whilst the lowest value was found in the 3-minute soaking treatment, namely 47.937. Meanwhile, on day 28, the highest L value was obtained in the 3-minute immersion treatment, namely 49.715, and the lowest value in the 2-minute immersion treatment, namely 48.354. All immersion time treatments showed no significant difference in L colour at the three observation times. These results indicate that variations in soaking time between 1 and 3 minutes do not have a significant effect on the brightness of Arabica coffee beans.

Colour a

Based on Table 5, the a-colour value of Arabica coffee beans in the treatments with different concentrations of Aloe vera nanocoating showed no significant difference during storage. On day 0, the highest a-colour value was observed at a concentration of 50 %, namely 5.341, whilst the lowest value was observed at a concentration of 0 % (control), namely 4.465. On day 14, the highest value was also found at a concentration of 50 %, namely 2.527, whilst the lowest value was found at a concentration of 0 %, namely 2.270. Furthermore, on day 28, the highest value was recorded at a concentration of 100 %, namely 2.783, whilst the lowest value was recorded at a concentration of 50 %, namely 2.392. The research results indicate that there were no significant differences across all concentration treatments at any observation time point. This indicates that the concentration of the Aloe vera nanocoating had no significant effect on the a-value of coffee beans during storage, as determined by the 5% DMRT test.

Table 5: Colour a of coffee beans as a function of the concentration of Aloe vera nanocoating and soaking time

Treatment	Colour a – Day 0		Colour a – Day 14		Colour a – Day 28	
Concentration Treatments						
0% concentration	4.465	a	2.270	a	2.748	a
25% concentration	4.521	a	2.279	a	2.402	a
50% concentration	5.341	a	2.527	a	2.392	a
100% concentration	4.776	a	2.306	a	2.783	a
Storage Duration Treatments						
1-minute immersion	4.402	a	2.231	a	2.590	a
2-minute immersion	5.318	a	2.423	a	2.192	a
3-minute immersion	4.608	a	2.383	a	2.962	a

Note: The mean values followed by the same letter in the same column are not significantly different according to the 5% DMRT test.

Based on the soaking time treatments, the a-value of the coffee beans on day 0 ranged from 4.402 to 5.318. The highest value was obtained in the 2-minute soaking treatment, namely 5.318, whilst the lowest value was found in the 1-minute soaking treatment, namely 4.402. On day 14, the highest value was also found in the 2-minute soaking treatment, namely 2.423, whilst the lowest value was found in the 1-minute soaking treatment, namely 2.231. Meanwhile, on day 28, the highest value was obtained in the 3-minute soaking treatment, namely 2.962, whilst the lowest value was found in the 2-minute soaking treatment, namely 2.192. All soaking time treatments showed no significant differences across the three observation periods. These results indicate that differences in soaking times of 1–3 minutes did not have a significant effect on the a-value of Arabica coffee beans.

Colour b

Based on Table 6, the b-colour value of Arabica coffee beans under the various concentrations of Aloe vera nanocoating treatments showed no significant difference during storage. On day 0, the highest b-colour value was observed at a concentration of 50 %, namely 19.621, whilst the lowest value was observed at a concentration of 25 %, namely 17.479. On day 14, the highest value was observed at a concentration of 100 %, namely 20.553, which was not significantly different from the value at 50 %, namely 20.519, whilst the lowest value was observed at a concentration of 25 %, namely 17.652. Furthermore, on day 28, the highest value was observed at a concentration of 50 %, namely 18.531, whilst the lowest value was observed at a concentration of 100 %, namely 17.319. No significant differences were observed across all concentrations at any observation time point. This indicates that the concentration of the Aloe vera nanocoating had no significant effect on the b colour value, as determined by the 5% DMRT test. Consequently, variations in the concentration of the nanocoating did not result in statistically significant differences in the blue–yellow colour components during storage.

Based on the soaking time treatments, the b-colour values of the coffee beans on day 0 ranged from 17.614 to 19.094. The highest value was obtained in the 1-minute soaking treatment, namely 19.094, whilst the lowest value was found in the 3-minute soaking treatment, namely 17.614. On day 14, the highest value was found in the 1-minute soaking treatment, namely 19.832, whilst the lowest value was found in the 2-minute soaking treatment, namely 19.020. Meanwhile, on day 28, the highest value was obtained in the 3-minute soaking treatment, namely 18.419, whilst the lowest value was found in the 2-minute soaking treatment, namely 16.903. The results of the study indicate that soaking times of 1–3 minutes had no significant effect on the b colour value of Arabica coffee beans.

Table 6: Colour b of coffee beans as a result of the effect of Aloe vera nanocoating concentration and soaking time

Treatment	Colour b – Day 0		Colour b – Day 14		Colour b – Day 28	
Concentration Treatments						
0% concentration	18.822	a	19.363	a	17.589	a
25% concentration	17.479	a	17.652	a	17.543	a
50% concentration	19.621	a	20.519	a	18.531	a
100% concentration	18.359	a	20.553	a	17.319	a
Storage Duration Treatments						
1-minute immersion	19.094	a	19.832	a	17.915	a
2-minute immersion	19.003	a	19.020	a	16.903	a
3-minute immersion	17.614	a	19.714	a	18.419	a

Note: The mean values followed by the same letter in the same column are not significantly different according to the 5% DMRT test.

Caffeine content (%)

Based on Table 7, the caffeine content of Arabica coffee beans in the treatments with different concentrations of Aloe vera nanocoating showed no significant difference during

storage. On day 0, the highest caffeine content was found at a concentration of 100 %, namely 1.850 %, followed by a concentration of 50 % at 1.840 %, whilst the lowest content was found at a concentration of 25 %, namely 1.614 %. On day 14, the highest caffeine content was also found at the 100 % concentration, namely 1.706 %, whilst the lowest values were found at the 25 % and 50 % concentrations, at 1.608 % respectively. Furthermore, on day 28, the highest caffeine content was found at a concentration of 100 %, namely 1.778 %, whilst the lowest content was found at a concentration of 50 %, namely 1.575 %. The results of the study indicate that there were no significant differences between the concentration treatments at any observation time point. This suggests that the concentration of the Aloe vera nanocoating had no significant effect on caffeine levels, as determined by the 5% DMRT test. Consequently, variations in the concentration of the nanocoating did not result in statistically significant differences in caffeine levels during storage.

Based on the steeping time treatments, the caffeine content of the coffee beans on day 0 ranged from 1.679–1.770 %. The highest content was obtained in the 3-minute steeping treatment, at 1.770 %, whilst the lowest content was found in the 1-minute steeping treatment, at 1.679 %. On day 14, the highest caffeine content was found in the 2-minute soaking treatment, at 1.687 %, whilst the lowest was in the 1-minute soaking treatment, at 1.573 %. Meanwhile, on day 28, the highest caffeine content was obtained in the 1-minute soaking treatment, at 1.732 %, whilst the lowest was found in the 2-minute soaking treatment, at 1.609 %. The results of the study indicate that differences in soaking time ranging from 1 to 3 minutes had no significant effect on the caffeine content of Arabica coffee beans.

Table 7: Caffeine content (%) in coffee beans as a function of the concentration of Aloe vera nanocoating and soaking time

Treatment	Caffeine Content (%) – Day 0		Caffeine Content (%) – Day 14		Caffeine Content (%) – Day 28	
Concentration Treatments						
0% concentration	1.621	a	1.658	a	1.622	a
25% concentration	1.614	a	1.608	a	1.675	a
50% concentration	1.840	a	1.608	a	1.575	a
100% concentration	1.850	a	1.706	a	1.778	a
Storage Duration Treatments						
1-minute immersion	1.679	a	1.573	a	1.732	a
2-minute immersion	1.744	a	1.687	a	1.609	a
3-minute immersion	1.770	a	1.675	a	1.645	a

Note: The mean values followed by the same letter in the same column are not significantly different according to the 5% DMRT test

Phenol content (%)

Based on Table 8, the phenolic content of Arabica coffee beans in the treatments with different concentrations of Aloe vera nanocoating showed no significant difference during storage. On day 0, the highest phenolic content was found at a concentration of 0% (control), namely 1.906 %, whilst the lowest content was found at a concentration of 25 %, namely 1.438 %. On day 14, the highest phenolic content was recorded at a concentration of 50 %, namely 2.206 %, followed by a concentration of 100 % at 2.100 %, whilst the lowest content was found at a concentration of 25 %, namely 1.625 %. Furthermore, on day 28, the highest phenol concentration was found at 50 %, namely 1.806 %, whilst the lowest concentration was found at 100 %, namely 1.541 %. Although there were variations in phenol concentration values between concentrations, all treatments showed no statistically significant differences. This indicates that the concentration of the Aloe vera nanocoating had no significant effect on phenol content, as determined by the 5% DMRT test.

Based on the soaking time treatments, the phenol content of the coffee beans on day 0 ranged from 1.523–1.819 %. The highest content was obtained in the 2-minute soaking treatment, at 1.819 %, whilst the lowest content was found in the 1-minute soaking treatment, at 1.523 %. On day 14, the highest phenolic content was found in the 3-minute soaking treatment, at 1.943 %, whilst the lowest was in the 1-minute soaking treatment, at 1.851 %. Meanwhile, on day 28, the highest phenolic content was obtained in the 3-minute soaking treatment, at 1.859 %, whilst the lowest was found in the 2-minute soaking treatment, at 1.514 %. All soaking time treatments showed no statistically significant differences across the three observation periods. These results indicate that differences in soaking times of 1–3 minutes do not have a significant effect on the phenolic content of Arabica coffee beans. Although the 3-minute soaking treatment produced the highest phenolic content on days 14 and 28, these differences merely indicated a trend and could not yet be declared statistically significant based on the 5% DMRT test.

Table 8: Phenol content (%) in coffee beans as a function of the concentration of Aloe vera nanocoating and soaking time

Treatment	Phenol Concentration – Day k-0		Phenol Concentration – Day k-14		Phenol Concentration – Day 28	
Treatment Concentration						
Concentration 0%	1.906	a	1.660	a	1.675	a
Concentration 25%	1.438	a	1.625	a	1.706	a
Concentration 50%	1.787	a	2.206	a	1.806	a
Concentration 100%	1.700	a	2.100	a	1.541	a
Treatment Storage Duration						
Immersion for 1 minute	1.523	a	1.851	a	1.673	a
Immersion for 2 minutes	1.819	a	1.899	a	1.514	a
Immersion for 3 minutes	1.781	a	1.943	a	1.859	a

Note: The mean values followed by the same letter in the same column are not significantly different according to the 5% DMRT test

Mould and yeast (Cfu/g)

Based on Table 9, the mould and yeast count (MYC) of Arabica coffee beans in the treatments with different concentrations of Aloe vera nanocoating showed changes during storage. On day 0, the FEC ranged from 2.2×10^2 cfu/g to 2.6×10^2 cfu/g, with the lowest value at a concentration of 25 % and the highest at a concentration of 100 %. All treatments showed FEC values that were not significantly different based on the 5 % DMRT test. On day 14, the highest MOULD AND YEAST COUNT value was found at a concentration of 0% (control), namely 5.2×10^2

cfu/g, whilst the lowest value was found at a concentration of 100%, namely 2.4×10² cfu/g. A concentration of 100% yielded a significantly different MOULD AND YEAST COUNT value compared with concentrations of 0%, 25% and 50%, indicating that the concentration of the nanocoating influences the MOULD AND YEAST COUNT midway through storage. On day 28, the highest MOULD AND YEAST COUNT value was found at a concentration of 0%, namely 6.2×10² cfu/g, whilst the lowest value was found at a concentration of 100%, namely 3.6×10² cfu/g, followed by a concentration of 50% at 4.0×10² cfu/g. The 0%, 25% and 50% and 100% concentration groups showed statistically significant differences. These results indicate that higher concentrations of Aloe vera nanocoating tend to be associated with lower mould and yeast count values during storage. The 100 % concentration showed a decrease in mould and yeast count from day 0 to day 28, whilst the control group experienced an increase. This pattern indicates the potential of Aloe vera nanocoating to inhibit the growth of mould and yeast on coffee beans.

Table 9: Mould and yeast counts (cfu/g) in coffee beans as a function of the concentration of Aloe vera nanocoating and soaking time

Treatment	Mould and yeast counts– Day k-0		Mould and yeast counts – Day k-0		Mould and yeast counts– Day k-0	
Treatment Concentration						
Concentration 0%	2.4 x 10^2	a	5.2 x 10^2	a	6.2 x 10^2	a
Concentration 25%	2.2 x 10^2	a	4.3 x 10^2	a	5.0 x 10^2	b
Concentration 50%	2.3 x 10^2	a	4.2 x 10^2	a	4.0 x 10^2	c
Concentration 100%	2.6 x 10^2	a	2.4 x 10^2	b	3.6 x 10^2	c
Treatment Storage Duration						
Immersion for 1 minute	2.3 x 10^2	a	4.4 x 10^2	a	4.8 x 10^2	b
Immersion for 2 minutes	2.5 x 10^2	a	4.4 x 10^2	a	5.9 x 10^2	a
Immersion for 3 minutes	2.2 x 10^2	a	3.4 x 10^2	a	3.4 x 10^2	c

Note: The mean values followed by the same letter in the same column are not significantly different according to the 5% DMRT test.

Based on the soaking time treatments, the mould and yeast count values on day 0 ranged from 2.2×10² to 2.5×10², with the lowest value observed in the 3-minute soaking treatment and the highest in the 2-minute soaking treatment; however, there was no statistically significant difference. On day 14, the highest mould and yeast count values were found in the 1-minute and 2-minute immersion treatments, at 4.4×10² respectively, whilst the lowest value was found in the 3-minute immersion treatment, at 3.4×10². The results of the study indicate a tendency for lower mould and yeast count values in the 3-minute immersion treatment; however, the DMRT 5% test showed that the differences between all treatments were not statistically significant. On day 28, the highest mould and yeast count value was observed in the 2-minute soaking treatment, namely 5.9×10^2, followed by the 1-minute soaking treatment at 4.8×10^2, whilst the lowest value was observed in the 3-minute soaking treatment, namely 3.4×10^2. The results of the study indicate that soaking time has a significant effect on mould and yeast count at the end of storage. the 3-minute immersion treatment produced the lowest mould and yeast count value, which differed significantly from the 1- and 2-minute immersion treatments. this suggests that a longer immersion time can enhance contact between the surface of the coffee beans and the nanocoating solution, thereby potentially resulting in a more uniform coating.

Scanning Electron Microscopy (SEM)

Observations using Scanning Electron Microscopy (SEM) on coffee beans treated with a 50 % concentration nanocoating for a 3-minute immersion period revealed the presence of a layer on the surface of the coffee beans, which is believed to be the coating material (Fig 1). Morphologically, the surface of the coffee beans appeared to be relatively covered by a layer with a texture that was not entirely homogeneous, characterized by areas of the surface that appeared smooth, rougher areas, and several small depressions or holes. The presence of a layer covering most of the surface indicates that the application of the nanocoating has the potential to form a protective layer on the surface of the coffee beans. This layer is thought to originate from the nanocoating material deposited during the immersion process, thereby helping to seal some of the pores or crevices on the surface of the coffee beans.

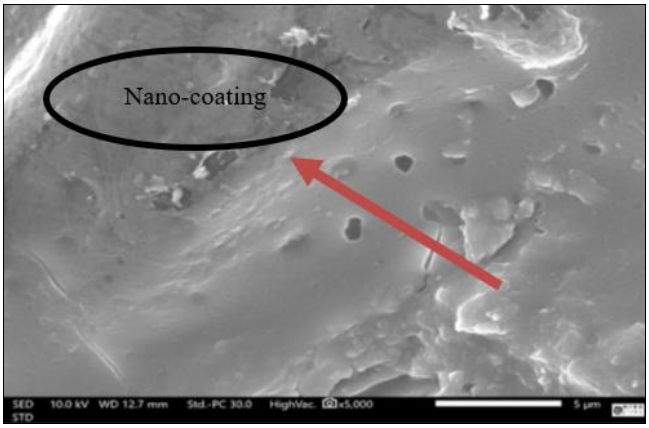


Fig 1: Scanning electron microscopy (SEM) observations of coffee beans treated with a 50 % nanocoating and a soaking time of 3 minutes

3.1 Discussion

The results of the study indicate that the concentration of the Aloe vera nanocoating and the immersion time had different effects on the quality characteristics of Arabica coffee beans (*Coffea arabica*) during 28 days' storage. The parameters observed included moisture content, water activity, L* colour, a* colour, b* colour, caffeine content, phenolic content, and mould and yeast count. Based on the results of statistical analysis, a significant effect of treatment was observed on the mould and yeast count, whilst the colour parameters, caffeine content, and phenolic content did not show any significant differences between treatments. These results indicate that the application of Aloe vera nanocoating has the potential to provide protection against microbiological spoilage without causing significant changes to several physical and chemical characteristics of the coffee beans. This potential is consistent with the research by Nicolau-Lapeña *et al*. (2021) [12], which explains that Aloe vera gel possesses antimicrobial and antioxidant activity and is capable of helping to maintain phenolic content and product quality during storage. Furthermore, Kumar *et al*. (2022) [9] suggest that the bioactive compounds in Aloe vera have the potential to be utilised in the development of active coatings to enhance the safety and

extend the shelf life of food products.

The moisture content of the coffee beans indicated that the concentration of the Aloe vera nanocoating had a very significant effect on day 0, but no significant effect on days 14 and 28. Based on the observations, the moisture content of Arabica coffee beans (*Coffea arabica*) tended to increase during the 28-day storage period. This increase is thought to be related to the hygroscopic nature of coffee beans, which allows them to absorb water vapour from the environment, particularly when the relative humidity of the air is higher than the equilibrium moisture content of the beans. Changes in temperature, relative humidity and packaging type during storage can affect water vapour transfer, thereby causing changes in the moisture content of coffee beans. This is consistent with the research by Anokye-Bempah *et al*. (2023) [2], which explains that fluctuations in temperature and relative humidity during storage and transport can cause changes in moisture content and water activity in green coffee beans. Błaszkiewicz *et al*. (2023) [3] also reported that coffee beans are hygroscopic and can therefore absorb moisture from the environment during storage. Consequently, the observed trend towards increased moisture content in this study is thought to indicate the absorption of water vapour from the environment during storage, although this mechanism requires confirmation through data on relative humidity and storage temperature.

Water activity exhibited a different response pattern compared with moisture content during the storage of Arabica coffee beans (*Coffea arabica*). The concentration of the Aloe vera nanocoating had a significant effect on water activity on day 0 and a highly significant effect on day 14, but no significant effect on day 28. Meanwhile, the soaking time showed no significant effect on water activity throughout the observation period. These results indicate that the concentration of the nanocoating is associated with changes in water activity, particularly during the early to mid-storage stages, whilst differences in concentration no longer showed a statistically significant effect by the end of storage. Water activity is a key parameter in determining the microbiological stability of foodstuffs, as it reflects the availability of water that can be utilized by microorganisms, rather than simply the total amount of water present in the material. Mould growth is influenced by water activity, temperature, the species of microorganism, and environmental conditions during storage. In the context of coffee beans, Estrada-Bahena *et al*. (2022) [6] discussed the relationship between water activity, fungal growth, and the potential for ochratoxin A formation during storage. Therefore, the relatively low water activity value observed in the 100% concentration Aloe vera nanocoating treatment on day 14 may indicate conditions that are less flavor able for the growth of certain moulds. The absence of a significant effect of nanocoating concentration on day 28 also suggests that the water activity response may change with the duration of storage. This may be related to the attainment of a moisture equilibrium between the coffee beans and the environment, the characteristics of the nanocoating layer, or variations in storage conditions (Anokye-Bempah *et al*., 2023) [2].

The concentration of the Aloe vera nanocoating and the soaking time showed no significant effect on the L, a, or b values on days 0, 14 and 28. The L value indicates the level of brightness, the a value describes the green–red colour component, whilst the b value describes the blue–yellow colour component. Although the values of these three colour parameters changed during storage, the differences between treatment levels were not significant based on the 5% DMRT test. These results indicate that the nanocoating treatment has not yet produced statistically detectable differences in colour characteristics. These findings are generally consistent with the study by Trujillo-Carretero *et al*. (2022) [18] on the physicochemical and biological characteristics of green Arabica coffee during storage, which emphasized the importance of storage conditions in maintaining coffee quality. Nevertheless, the absence of any significant differences between treatment levels in this study does not directly prove that the colour of the coffee beans remains entirely stable over a 28-day period.

The caffeine content of Arabica coffee beans (*Coffea arabica*) showed no significant difference as a result of the Aloe vera nanocoating concentration or the soaking time across the entire observation period. These results indicate that the variations in concentration and soaking time applied did not result in any statistically detectable changes in caffeine content during storage. A similar pattern was also observed for phenolic content, which showed no significant effect from either treatment factor. The lack of a significant effect from these treatments indicates that, under the conditions of this study, the use of Aloe vera nanocoating has not been shown to significantly alter the levels of these two chemical components. Strocchi *et al*. (2023) [15] reported that the phenolic and alkaloid fractions remain relatively stable in coffee during storage; however, some compounds, including caffeine and caffeic acid, may undergo degradation under conditions of higher relative humidity. Furthermore, Zarebska *et al*. (2022) [19] evaluated changes in the chemical composition of green coffee, including caffeine and chlorogenic acid, during storage under varying temperatures and packaging types. The study showed that changes in the chemical composition of coffee can vary depending on storage conditions and post-harvest processing. Consequently, the absence of any significant differences in caffeine and phenolic levels in this study indicates that the Aloe vera nanocoating treatment did not have a statistically significant effect on these two parameters during the 28-day storage period.

The results of the study show that an increase in the concentration of Aloe vera nanocoating tends to be accompanied by a reduction in the mould and yeast count on the 14th and 28th days of storage. These results indicate the potential of Aloe vera nanocoating to help control the growth of microorganisms during the storage of Arabica coffee beans (*Coffea arabica*). One possible mechanism is the presence of bioactive compounds in Aloe vera that have the potential to inhibit the growth of microorganisms (Nicolau-Lapeña *et al*., 2021) [12]. Sempere-Ferre *et al*. (2022) [14] reported that Aloe vera extract inhibited the growth of several fungi *in vitro* on blueberries. In addition to concentration, longer immersion times also tend to result in lower mould and yeast count values. This is thought to be related to the longer contact time between the coffee bean surface and the nanocoating solution, which may influence the formation and uniformity of the coating on the bean surface (Priya *et al*., 2023) [13].

Observations using Scanning Electron Microscopy (SEM) on Arabica coffee beans treated with a 50 % concentration of Aloe vera nanocoating for 3 minutes revealed the presence of a layer of coating material on the surface of the

coffee beans (Fig 1). Morphologically, the surface of the coffee beans appeared to be relatively covered by a layer with characteristics that were not entirely homogeneous, characterized by relatively smooth sections, rougher areas, and several small depressions and holes. This indicates that the coating material had been deposited on most of the coffee bean surface, although its distribution was not yet perfectly uniform. These findings are consistent with those of Suriati *et al*. (2022) [16], who explained that the morphological characteristics of Aloe vera-based gel coatings are influenced by the physical properties of the solution, particularly viscosity and surface tension, which play a role in the adhesion and coating formation processes. Furthermore, Kaur *et al*. (2024) [8] demonstrated that a combination of Aloe vera and chitosan is capable of forming a film structure with a relatively smooth surface morphology and water vapour barrier properties. Functionally, the film formed on the surface of coffee beans has the potential to reduce direct contact with the external environment and limit moisture transfer and the ingress of contaminants. This is supported by Tarangini *et al*. (2022) [17], who, through SEM observations, demonstrated that the application of an edible coating is capable of forming a relatively smooth and continuous semi-permeable layer on the surface of tomatoes. Nevertheless, the presence of small depressions and holes in the SEM images of coffee beans indicates that the formation of the layer is not yet entirely uniform. Therefore, the 50 % concentration Aloe vera nanocoating treatment with a 3-minute immersion time shows potential for forming a protective layer on the surface of Arabica coffee beans, although its effectiveness in inhibiting water vapour transfer and microbial contamination still needs to be confirmed through further testing.

Overall, this study indicates that Aloe vera nanocoating has the potential to be used as a natural preservative technology to help control the growth of mould and yeast on Arabica coffee beans during storage. The most consistent effect was observed in the mould and yeast count parameter, whilst colour, caffeine content and phenolic content showed no significant differences between treatments. The results for moisture content and water activity indicate that the response to treatment depends on the observation time; therefore, its effect needs to be assessed in conjunction with storage conditions and changes in microbiological characteristics. Nevertheless, this study has not yet proven that the nanocoating is capable of eliminating all mould or guaranteeing the safety of the coffee from mycotoxins. Further testing regarding mould identification, mycotoxin formation, particle and coating size characterization, as well as sensory quality evaluation, is required to strengthen the evidence of the effectiveness and safety of Aloe vera nanocoating technology in Arabica coffee.

The Best Treatment

Based on the results of the statistical analysis of water activity (Aw), a 50 % concentration of Aloe vera nanocoating can be considered the optimal concentration, taking into account both effectiveness and efficiency of material use. On day 14, the 50 % concentration yielded an Aw value of 0.600, which was not significantly different from the 100 % concentration, which yielded a value of 0.591. On day 28, the two treatments also showed no significant difference, with Aw values of 0.629 and 0.624 respectively. These results indicate that increasing the concentration from 50 % to 100 % did not result in a significant difference in water activity at either of these observation points. This finding is further supported by the results of the mould and yeast count test on day 28, when the 50 % concentration yielded a value of 4.0×10^2 cfu/g and the 100 % concentration yielded a value of 3.6×10^2 cfu/g, which were not statistically significantly different based on the 5 % DMRT test. Consequently, the 50 % concentration can be selected as a more efficient alternative as it yields results that are statistically comparable to those of the 100 % concentration for both parameters.

The rationale for selecting these concentrations is consistent with the study by Sempere-Ferre *et al*. (2022) [14], which evaluated the antifungal activity of Aloe vera gel against several post-harvest fungi. That study showed that the ability to inhibit fungi varied depending on the gel concentration and the type of fungus tested. For some fungi, antifungal activity was still observed at lower concentrations, whilst greater inhibition was found at specific concentrations. These findings suggest that higher concentrations of the coating agent need not always be selected if lower concentrations already yield comparable results for the target parameters. Furthermore, Kumar *et al*. (2022) [9] explain that Aloe vera gel has the potential to be used as an active coating agent in food preservation due to its film-forming characteristics and its content of bioactive compounds.

A soaking time of 3 minutes was determined to be the optimal soaking time based on the mould and yeast count test results on day 28. This treatment yielded the lowest mould and yeast count value, namely 3.4×10^2; this compares with a value of 4.8×10^2 cfu/g for the 1-minute soaking treatment and 5.9×10^2 cfu/g for the 2-minute soaking treatment. All three treatments showed significant differences based on the 5% DMRT test, indicating that the 3-minute immersion provided better control of mould and yeast at the end of storage. The research results indicate that a longer contact time allows the coating solution to wet the surface of the coffee beans more evenly. Hasan *et al*. (2021) [7] also reported the potential of Aloe vera gel coating in maintaining quality and extending the shelf life of fruit and vegetables.

4. Conclusion

The concentration of the Aloe vera gel-based coating had a significant effect on moisture content on day 0, water activity on days 0 and 14, and mould and yeast counts on days 14 and 28. Soaking time had a significant effect on the mould and yeast count on day 28. No significant interaction was found between concentration and soaking time. Neither factor had a significant effect on the L*, a* and b* colour values, caffeine content, or total phenolic content during the 28-day storage period. A 100 % concentration resulted in the lowest mould and yeast counts on day 14 (2.4×10^2 CFU/g) and day 28 (3.6×10^2 CFU/g), whilst a 3-minute soaking time yielded the lowest value on day 28 (3.4×10^2 CFU/g). A 50% concentration may be considered a more efficient alternative, as the mould and yeast counts on day 28 were not significantly different from those of the 100% concentration, based on DMRT grouping. Aloe vera coatings have the potential to help control mould and yeast, but confirmation of the nanoparticle characteristics, fungal identification, mycotoxin analysis and sensory quality testing are still required.

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