Malays. J. Bioeng. Technol. Vol. 1, No. 2, (2024): 154-160
https://doi.org/10.70464/mjbet.v1i2.1477

MALAYSIAN JOURNAL OF BIOENGINEERING AND TECHNOLOGY

Effect of Polyvinyl Alcohol (PVA), Cellulose Nanocrystals (CNC), and ε-Polylysine (ε-PL) Biocomposites for Fresh Chillies Coating Application

Nur Aiman Mohamad Senusi[1], Nor Hakimin Abdullah[2,*]

Faculty of Bioengineering and Technology, Universiti Malaysia Kelantan, 17600 Jeli, Kelantan, Malaysia

**Corresponding author: norhakimin@umk.edu.my*

ARTICLE INFO

Received:14 November 2024
Accepted:1 December 2024
Online:19 December 2024
eISSN: 3036-017X

ABSTRACT

The rising demand for fresh fruits and vegetables has resulted in considerable issues in post-harvest preservation, especially with weight loss and rotting. This study examines the efficacy of a biodegradable biocomposite coating made from polyvinyl alcohol (PVA), cellulose nanocrystals (CNC), and εpsilon polylysine (ε-PL) in prolonging the shelf-life of chilies. The investigation specifically analyses the post-harvest performance of chilies with and without stems when treated with 17 solutions of PVA/CNC/ε-PL biocomposite suggested by the Response Surface Method (RSM). The fresh chilies were dipped into the PVA/CNC/ε-PL biocomposite solution for 30 seconds, weight loss inspection of the chilies was evaluated in 21 days, and stored in the chiller at 9 °C. Findings demonstrate that stemless chilies coated with the nanocomposite experience markedly reduced weight loss, which gains the lowest weight loss results of 5.92 % during storage in comparison to their stem chilies, the lowest weight loss result is 17.5 %. The protective layer significantly diminished moisture loss and preserved fruit firmness, hence enhancing freshness duration. The stemless chilies, coated with the PVA/CNC/ε-PL nanocomposite, exhibited enhanced preservation properties, indicating that the lack of stems, along with the coating formulation, improves the fruit's resistance to dehydration and decay. This work demonstrates that PVA/CNC/ε-PL nanocomposites may serve as a novel, eco-friendly approach to diminish waste and enhance the shelf-life of fresh products. The results suggest favorable consequences for sustainable agriculture, minimizing food waste and enhancing supply chain logistics. Future research may investigate the scalability of this method and its applicability to other perishable fruits and vegetables.

Keywords: Biodegradable coatings; post-harvest preservation; weight loss; shelf-life; food waste.

1. Introduction

1.1 Background and Importance of Fresh Produce

Fresh fruits and vegetables are crucial to a balanced diet because they include important nutrients, vitamins, and minerals that promote general health and well-being. They play an important role in the prevention of chronic diseases such as obesity, diabetes, and cardiovascular disorders. Thus, their consumption is recommended as part of global public health guidelines. In addition to its nutritional value, fresh produce promotes food security and makes major contributions to local and global economies, particularly in the agricultural sectors where it is grown [1].

The global market for fresh fruits and vegetables is quickly expanding, owing to rising consumer awareness of good eating habits and a desire for natural, minimally processed foods. Despite its value, fresh produce is extremely perishable, with a short shelf life determined by temperature, humidity, and handling techniques. This perishability causes large post-harvest losses, with estimates indicating that up to 30% of fruits and vegetables produced are discarded before they reach customers. These losses not only reduce food supply but also contribute to environmental damage since rejected produce emits greenhouse gases during decomposition [2].

The problem of decreasing waste while ensuring the quality and safety of fresh produce is critical. Innovative preservation strategies are required to increase the shelf life, reduce spoiling, and improve the overall freshness of these perishables. This is where biodegradable nanocomposite coatings appear as a possible answer. By inventing sustainable and effective solutions to keep fresh produce, we can help ensure that more fruits and vegetables reach customers, boosting food security, encouraging better diets, and minimizing the environmental impact of food waste.

In this research, polyvinyl alcohol (PVA), cellulose nanocrystals (CNC), and epsilon polylysine (ε-PL) biocomposite were tested on fresh chilies by dipping method. The freshness of the chilies samples was observed by weight loss inspection of the chilies for 21 days and stored in the chiller at 9 °C.

2. Materials and Methods

2.1 Preparation of PVA

The 2 wt.% PVA solution was first made by dissolving 2 grams of PVA powder in 100 mL of distilled water and stirring at 90 °C for 90 minutes [3]. Likewise, to dissolve 5 wt.% and 8 wt.% of PVA. Stir the solution overnight [4].

2.2 Preparation of PVA/CNC/ε -Polylysine Nanocomposites

Heat the PVA solution around 45 °C, then add 1g/4g/7g (refer to Table 1) of CNC powder. After the solution was mixed well, 1, 3, or 5 g of ε-polylysine (ε-PL) was added, as shown in Table 1. PVA/CNC/ε-polylysine nanocomposites solution was homogenized using a homogenizer for 15 minutes.

Table 1: Amount of PVA, CNC, and ε-polylysine (ε-PL) suggested by Response Surface Method (RSM).

RUN	PVA (wt.%)	CNC (wt.%)	E-polylysine (wt.%)
1	5	1	1
2	2	7	3
3	5	1	5
4	5	4	3
5	5	7	1
6	5	4	3
7	5	4	3
8	5	7	5
9	8	4	1
10	5	4	3
11	2	4	5
12	8	7	3
13	2	4	1
14	5	4	3
15	8	1	3
16	2	1	3
17	8	4	5

2.3 Preparation of Chili Coating

The amount of 378 chilies was selected to prepare 21 samples (with stem and without stem) for this experiment. In Fig. 1, selected chilies were cleansed with running water, rinsed with distilled water, drained, and air-dried at room temperature [5]. Weight the chili before coating it with PVA/CNC/ε-PL. Recorded the weight of the chilies before coating. Dip the chili into PVA/CNC/ε-polylysine nanocomposites solution for 30 seconds for each chili. Then dry the chilies overnight until they dry (2 days), as shown in Fig. 1. After the chilies are dry, they are stored in the chiller at 9 °C.

(a) (b)

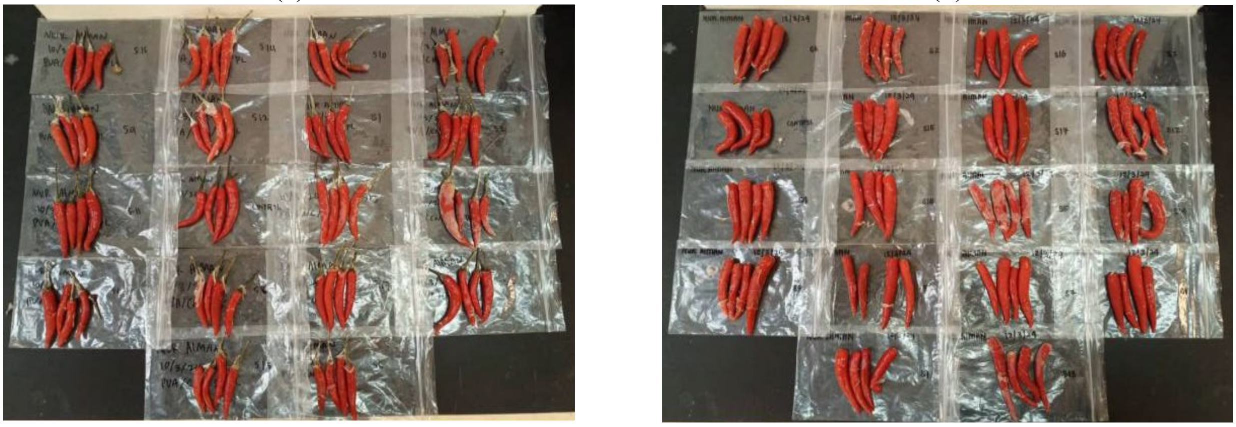

Fig. 1: Physical condition of chilies, (a) with stem, and (b) without stem after two days of drying process

2.4 Weight Loss (%)

Weight loss in fruits and vegetables is a critical factor influencing their quality, marketability, and nutritional value. This phenomenon primarily results from moisture loss, which occurs through processes such as transpiration and respiration. Transpiration refers to the evaporation of water from the surface of the produce, while respiration encompasses the metabolic processes that consume oxygen and release carbon dioxide, resulting in the degradation of tissue and loss of weight. Therefore, effective management strategies, such as optimal storage conditions and the application of protective coatings, are vital for minimizing weight loss, thereby enhancing the longevity and quality of fresh produce [6].

Fruit loss of weight is related to skin transpiration and respiration. The water pressure difference between the fruit tissue and the surrounding air, as well as the storage temperature, determine how quickly water is lost. Fruits that are dehydrated also have more surface wounds. Fruit skin is shielded from mechanical damage by edible coatings, which also serve as barriers by sealing minor wounds and preventing dehydration.

The percentage of weight loss was determined based on the loss in weight during storage. The weight loss % was determined using the equation shown below:

$$\text{Weight loss percentage} = (\text{Weight loss} / \text{Initial weight}) \times 100 \quad (1)$$

3. Results and Discussion

3.1 Weight Loss of Chilies

3.1.1 Weight Loss of Chilies (with stem)

From Fig. 2 below, the lowest weight loss of chilies (with stem) coated with PVA/CNC/E-PL nanocomposite coating for 21 days was sample S14 which 17.5% weight loss, followed by S5, Control, S1, S13, S11, S12, S4, S6, S3, S8, S17, S9, S16, S10, S7, S15 and S2 which resulted 17.56, 18.9, 20.51, 20.65, 21.55, 23.71, 24.48, 24.66, 25.6, 25.73, 25.92, 26, 26.4, 26.41, 26.6, 27.36 and 29.59 % respectively.

eISSN Number: 3036-017X

The weight loss data for chilies coated with PVA/CNC/E-PL nanocomposite coatings over a 21-day period demonstrates varying degradation levels, reflecting the differing protective efficacy of the coatings. Sample S14 demonstrated the lowest weight loss at 17.5%, indicating that this particular coating formulation provides the most effective protection against degradation, likely attributable to the optimal combination of the polymer matrix and nanocomposite components. S5, Control, and S1 exhibited weight losses between 17.56 and 20.65%, indicating moderate protection, albeit to a lesser extent than S14. The results indicate that the PVA/CNC/E-PL nanocomposite coating demonstrates considerable enhancement compared to uncoated controls; however, variations in structural or chemical properties among some samples may affect the coating's efficacy.

Conversely, samples S2, S15, S7, and S10 exhibited weight losses between 26.6 and 29.59%, signifying the highest degradation and suggesting that these coatings were less effective in mitigating moisture loss or microbial activity. The incremental weight loss observed from S14 to S2 indicates that differences in the coating's composition, thickness, or application method significantly affect the performance of the protective layer. The Control sample, which lacked any coating, exhibited a weight loss of 20.51 %. This observation supports the notion that nanocomposite coatings effectively mitigate degradation, although the level of protection is contingent upon the specific formulation employed. The findings highlight the necessity of optimizing coating composition and application processes to enhance the preservation of perishable items such as chilies [7].

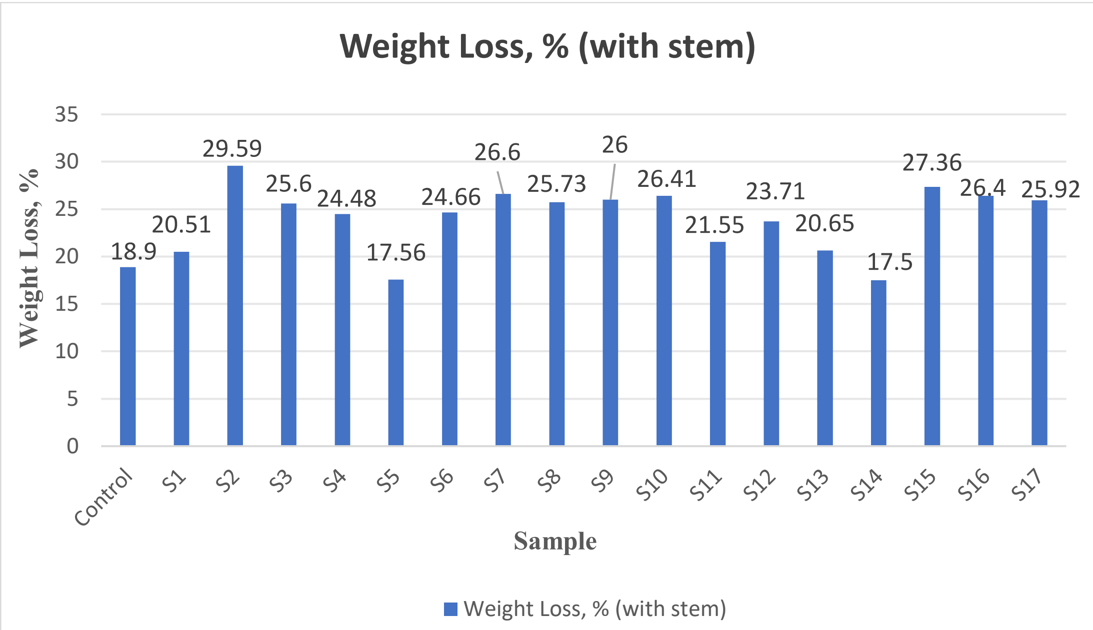

Fig. 2: Weight loss of chilies (with stem) coated with PVA/CNC/E-PL nanocomposite coating for 21 days

3.1.2 Weight Loss of Chilies (without stem)

From Fig. 3 below, the lowest weight loss was sample S5, which was 5.92% weight loss, and the highest percent of weight loss was sample S17, which resulted in 11.55 %.

The weight loss results from the samples demonstrate sample S5 exhibits the lowest weight loss at 5.92%, indicating it is the best under the experimental conditions. Subsequently, samples S12, S7, S2, and others demonstrate marginally elevated losses, ranging from 6.04% to 7.97%. The observed low weight loss in these samples indicates relative stability; however, some degradation is evident, likely attributable to variations in chemical composition, molecular structure, or other protective factors that enhance resistance.

Conversely, samples S11, S10, and S3 exhibit moderate degradation, with weight losses ranging from 8.35% to 8.53%. In contrast, samples S14, S8, and S17, which experience greater weight losses of up to 11.55%, indicate a higher susceptibility to degradation. This pattern indicates that specific samples, especially those exhibiting elevated degradation rates, may demonstrate reduced stability attributable to factors such as weaker molecular bonds or the presence of more reactive compounds. The control sample exhibited a weight loss of 9.05%, establishing a baseline for

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comparison, with certain samples demonstrating superior performance and others inferior performance. The data indicates varying material stabilities, and analyzing the specific traits of the more resilient samples may enhance material longevity in analogous applications.

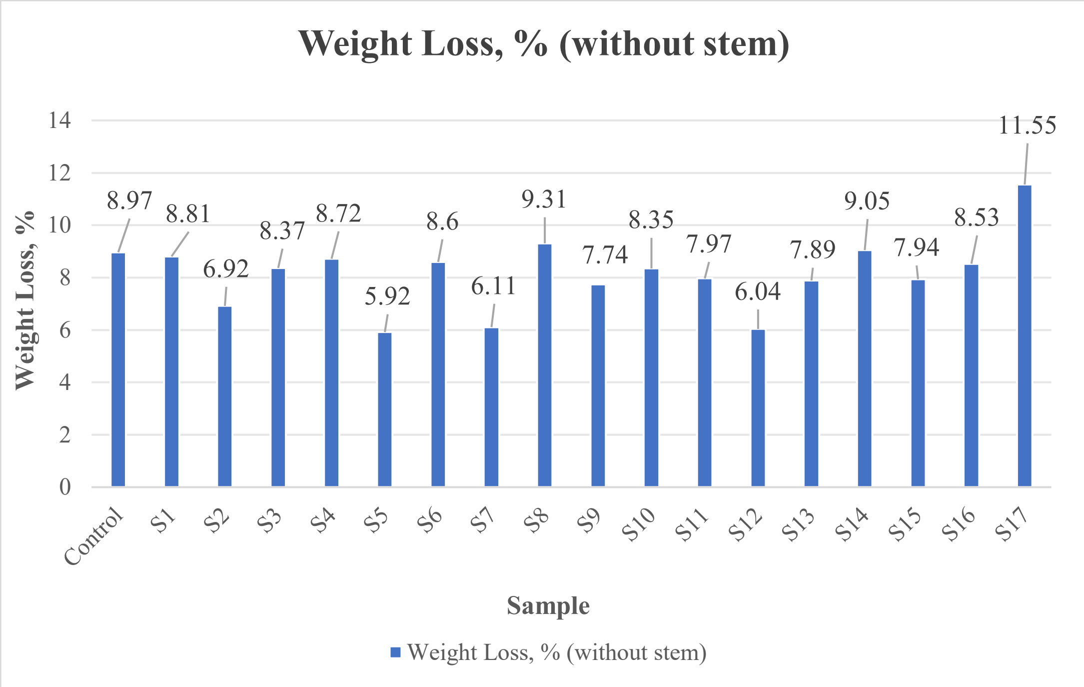

Fig. 3: Weight loss of chilies (without stem) coated with PVA/CNC/E-PL nanocomposite coating for 21 days

3.2 Comparison Between Weight Loss of Chilies with Stem and Without Stem

Chilies devoid of stems typically possess an extended shelf life and enhanced freshness relative to those with stems, as stem removal diminishes the potential for bacterial proliferation. The stem area serves as an optimal location for moisture retention, perhaps fostering the proliferation of mold and fungi, especially in warm or humid conditions. Storing chilies with their stems intact might expedite spoiling due to moisture retention in that area, resulting in the chilies becoming soft or rotting more rapidly. Eliminating the stem facilitates quicker drying of the chili, minimizing extra moisture that may lead to deterioration, thus prolonging its freshness.

Moreover, chilies without stems are better in refrigeration. Stemless chilies compress more readily when kept in a sealed container or plastic bag, therefore limiting air and oxygen exposure and so retaining their freshness. Since chilies can be packed securely and consistently without the bulky stem creating unequal freezing or space inefficiencies, their removal also makes freezing simpler. Chilies without stems freeze better than those kept with the stem and last far longer while maintaining their taste and texture.

Finally, the absence of the stem may decrease physical damage during storage and handling. Stems are prone to bruising and breaking off, particularly in bulk packaging or when chilies are stacked. These damaged stems can produce gaps in the chili, causing the fruit to degrade more quickly. Chilies without stems are less susceptible to this form of damage, allowing them to retain their quality for a longer period of time. Stemless chilies have a smoother, more uniform surface, which makes them less prone to contamination, extending their freshness and durability.

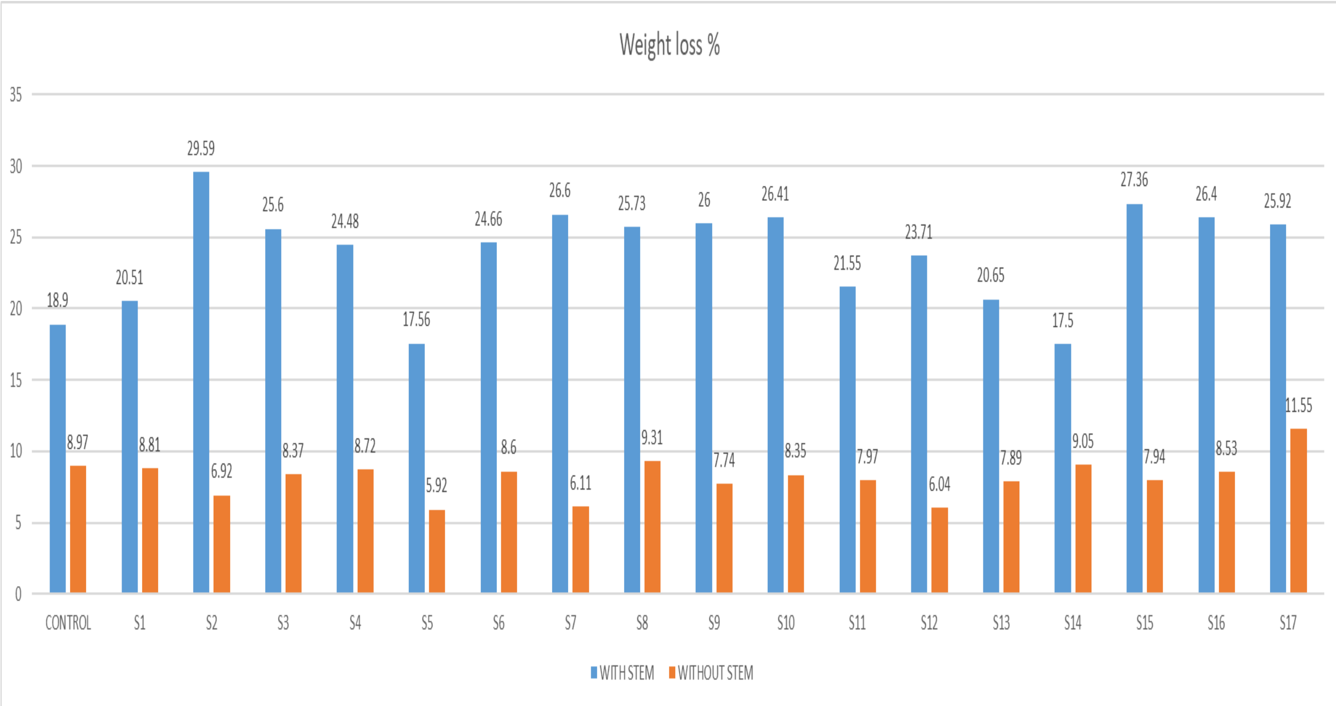

Fig. 4: Weight loss of chilies (with stem and without stem) coated with PVA/CNC/E-PL nanocomposite for 21 days stored in a chiller at 9 °C

4. Conclusion

In conclusion, the study indicates the benefits of stemless chilies coated with a PVA/CNC/Epsilon polylysine nanocomposite, notably in terms of decreased weight loss relative to chilies with stems. The stemless chilies, coated with the nanocomposite, exhibited enhanced moisture retention and reduced dehydration during storage, hence improving their preservation [8]. The diminished weight loss signifies that the coating successfully alleviates post-harvest desiccation, implying that stemless chilies may provide a more efficient and sustainable method for prolonging shelf life. These findings highlight the prospective advantages of this nanocomposite coating in enhancing the preservation and quality of chilies, especially in commercial and supply chain contexts. Future studies may investigate the fundamental mechanisms contributing to diminished weight loss and enhance the formulation for wider agricultural applications.

Acknowledgment

The authors would like to acknowledge the Ministry of Higher Education (MOHE), Malaysia, for the awarded grant, namely the Malaysian Fundamental Research Grant Scheme (FRGS) (FRGS/1/2023/TK09/UMK/02/3).

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