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Weight loss dynamics of banana under different packaging conditions

Dinámica de la pérdida de peso del plátano en diferentes condiciones de envasado

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Abstract: The aim of this study was to model the percentage of weight loss in banana during postharvest storage under different packaging conditions over time. Three treatments were evaluated: no polyethylene bag (control treatment), non-perforated polyethylene bag and perforated polyethylene bag. Weight of banana clusters was monitored over a 27-day storage period, with measurements taken at 12 time points. Weight loss was expressed as a percentage of initial weight. A color-based maturity chart was used to describe ripeness stage at 0, 19 and 27 days after harvest. The Shapiro-Wilk test was used to test for normality and ANOVA was carried out to test for statistical differences among treatments. The observed patterns are consistent with known physiological processes, and the differences among treatments coincides with other studies where packaging conditions affected variables like weight loss.

Keywords: banana, postharvest, polyethylene packaging, exports.

Resumen

El objetivo de este estudio fue modelizar el porcentaje de pérdida de peso de los plátanos durante el almacenamiento poscosecha en diferentes condiciones de envasado a lo largo del tiempo. Se evaluaron tres tratamientos: sin bolsa de polietileno (tratamiento de control), bolsa de polietileno no perforada y bolsa de polietileno perforada. Se realizó un seguimiento del peso de los racimos de plátanos durante un periodo de almacenamiento de 27 días, con mediciones tomadas en 12 momentos distintos. La pérdida de peso se expresó como porcentaje del peso inicial. Se utilizó una tabla de madurez basada en el color para describir el estado de maduración a los 0, 19 y 27 días tras la cosecha. Se aplicó la prueba de Shapiro-Wilk para comprobar la normalidad de la distribución y se realizó un ANOVA para evaluar las diferencias estadísticas entre los tratamientos. Los patrones observados concuerdan con los procesos

fisiológicos conocidos, y las diferencias entre los tratamientos coinciden con otros estudios en los que las condiciones de envasado afectaron a variables como la pérdida de peso.

Palabras clave: plátano, poscosecha, envasado en polietileno, exportaciones.

Introduction

Banana (*Musa spp.*) export is one of the main economic activities in Ecuador. It is the country's second-largest source of income after oil, and as such, it contributes significantly to the national economy (Orozco, 2017; León Ajila et al., 2023).

In the postharvest context, quality is key for the product acceptance in international markets. One of the factors that has gained increasing importance in recent years is the weight of banana clusters. Many retailers attempt to standardize the bananas displayed on shelves by establishing a specific weight range. This creates several challenges at farm level and throughout the commercialization chain. Since banana bunches are naturally heterogeneous in shape and size rather than being perfectly uniform (Guo et al., 2021) enforcing a specific weight range results in low bunch utilization.

Regarding the commercialization chain, because banana is a climacteric fruit, it undergoes physiological processes such as respiration and ripening after being harvested (Maduwanthi, 2017), which lead to weight loss that may compromise the specifications required by customers.

Understanding the dynamics of weight loss during storage and transport is therefore essential to optimize fruit utilization at the packing facility and to ensure that the product reaches customers within the requested specifications.

During both land and maritime transport, which usually lasts between 16 and 23 days for the United States and the European Union, respectively, bananas lose weight due to dehydration caused by physiological processes. This loss may prevent the product from meeting the commercial specifications required by customers, leading to rejections, claims, and economic losses (Al-Dairi et al, 2023). Heat generated by respiration may also induce quality issues (Jedermann et al, 2017).

The type of packaging depends on the needs and preferences of retailers or ripening operators. Some prefer perforated bags and controlled-atmosphere containers, as these allow gas exchange to occur more

easily during controlled ripening, while others prefer non-perforated bags and standard containers (no controlled atmosphere) due to the lower cost of the latter.

Different types of packaging have been shown to significantly affect the green life and weight loss of the fruit (Hailu et al., 2014). Therefore, research is needed to evaluate and compare banana weight loss under different packaging conditions, generating useful information for decision-making in postharvest management.

Theoretical Framework

Background

Several studies have addressed the issue of weight loss in bananas during postharvest storage and transport, highlighting the influence of physiological and technological factors, such as the type of primary packaging.

Hailu et al. (2014) evaluated the effect of different packaging materials on banana shelf life and quality, finding that packaging type significantly influences weight loss and quality preservation. The authors showed that packaging with lower gas exchange tends to reduce fruit dehydration.

Marriott (1979), in turn, described the physiological processes associated with banana ripening, indicating that respiration and water loss are determining factors in weight reduction during storage.

Maduwanthi (2017) analyzed biochemical changes during banana ripening, highlighting that increased respiratory activity accelerates metabolic processes that indirectly contribute to fruit mass loss.

Prasad et al. (2014) indicated that bananas packed in polyethylene bags have a longer shelf life than those exposed to the environment.

Despite these advances, there are still gaps in the literature regarding direct comparisons between specific types of packaging, such as perforated and non-perforated bags, under storage conditions. Additionally, there is limited research on the mathematical modeling of banana weight loss dynamics. These gaps justify conducting the proposed study.

Theoretical Basis

Banana as a climacteric fruit. Banana (*Musa spp.*) is a climacteric fruit, meaning that it continues its ripening process after harvest. This

process is characterized by an increase in respiration rate and ethylene production, which accelerates physiological and biochemical changes in the fruit (Maduwanthi, 2017).

Postharvest respiration and transpiration. Respiration is a metabolic process through which the fruit consumes oxygen and releases carbon dioxide, water, and energy, indirectly contributing to mass loss. Transpiration consists of water loss in the form of vapor from fruit tissues to the environment. Transpiration is the main mechanism responsible for postharvest weight loss in fruits (Pérez, 2014).

Weight loss and commercial quality. Weight loss in fruits is a key quality indicator, as it is associated with physiological deterioration and is one of the main indicators of compliance with commercial standards. In bananas, this loss occurs mainly due to transpiration (the primary factor) and respiration. A weight below commercial specifications may lead to partial or total rejection of the shipment at destination, generating significant economic claims for traders and/or producers. This is especially critical in markets that require specific weight ranges (Khodabakhshian and Baghbani, 2021).

Influence of packaging. Packaging plays a fundamental role in postharvest preservation, as it regulates gas exchange and moisture loss. Two relevant types in this study are:

- Perforated packaging: allows greater gas exchange, higher water loss, and lower CO₂ accumulation.
- Vacuum or non-perforated packaging: reduces transpiration and limits gas exchange.

According to Hailu et al. (2014), differences in packaging material permeability directly influence the rate of weight loss.

Woldetsadik et al. (2015) reported that polyethylene packaging materials reduced physiological weight loss in banana fruits compared with unpackaged fruits, highlighting the role of packaging in reducing moisture loss during postharvest storage.

Ahmad et al. (2006) reported that polyethylene packaging reduced weight loss and maintained greater firmness in banana fruits during storage, suggesting that polyethylene packaging can limit moisture loss and delay postharvest deterioration.

Paulos and Ayalew (2020) demonstrated that packaging materials influenced the storability and physicochemical quality of bananas, with

some packaging systems contributing to reduced weight loss during storage.

Zerga (2020) found that packaging materials significantly affected physiological weight loss and ripening-related quality attributes of banana fruits, with polyethylene packaging resulting in lower weight loss than the unpackaged control.

Storage conditions. Factors such as temperature and relative humidity influence weight loss. Moderate temperatures help slow respiration and reduce dehydration, therefore improving fruit preservation. Great emphasis is placed on all those aspects that increase the product's green life in order to facilitate transportation and marketing (Soto Ballesteros, 2017), even leading to the shipping industry building specialized reefer containers (Arduino et al, 2015).

Acharya et al. (2025) found that polyethylene packaging reduced physiological weight loss in banana fruits compared with unpackaged fruits, confirming the potential of polyethylene-based packaging to reduce postharvest moisture loss.

Temperature is an important factor controlling the rate of banana ripening and postharvest life. Lobo et al. (2005) demonstrated that the temperature during ethylene treatment influenced ripening behavior and subsequent fruit quality. Changes in respiration, soluble solids, pulp and peel firmness, sugars, and organic acids were associated with the temperature conditions applied during artificial ripening.

Ripening. Consumer acceptance of bananas is based mainly on its ripening stage, which makes being able to measure it extremely important (Sinanoglou et al, 2023).

Bananas need to undergo treatment with ethylene otherwise if they're left to ripe naturally the results are very inconsistent (Mahajan et al, 2010).

Thakur et al. (2019) demonstrated that delaying banana ripening through an edible coating was associated with reduced ethylene production, starch degradation, chlorophyll degradation, and fruit weight loss during storage.

Banana ripening is accompanied by substantial biochemical and physiological changes, particularly the conversion of starch into soluble sugars (Cordenunsi-Lysenko et al., 2019). Moreno et al. (2021) reported that storage time significantly affected several quality attributes,

including starch content, soluble solids, and peel color. These changes demonstrate that banana ripening is a dynamic process that can be monitored through physicochemical indicators and used to characterize different ripening stages.

During ripening and over-ripening, Cavendish bananas undergo progressive physiological, molecular, and ultrastructural changes that affect fruit tissue integrity. Ramírez-Sánchez et al. (2018) identified structural and molecular characteristics associated with programmed cell death during advanced stages of ripening. These processes may contribute to the progressive deterioration and loss of structural integrity observed as bananas advance toward over-ripening.

Wills et al. (1984) reported changes in starch, individual sugars, soluble solids, organic acids, pH, and other chemical components across different ripening stages. These findings indicate that peel color can serve as a practical indicator of ripening progression.

The maturity stage at harvest influences the subsequent rate of banana ripening. Madamba et al. (1977) found that bananas harvested at different maturity levels followed similar biochemical trends during ripening, although fruit harvested at a more advanced maturity stage reached the eating-ripe condition more rapidly. During ripening, starch content decreased while total sugars and soluble solids increased, particularly during the later stages of the process.

Firmness is one of the most evident physical characteristics affected by banana ripening. Finney et al. (1967) demonstrated that banana firmness decreased progressively as the fruit advanced from the green to the yellow stage. The reduction in firmness was associated with biochemical changes, including starch degradation and increasing concentrations of reducing sugars, indicating a close relationship between tissue softening and the biochemical progression of ripening.

Metabolic changes during banana ripening can differ among cultivars. Gao et al. (2025) identified numerous metabolites associated with ripening in six banana cultivars, including soluble sugars, organic acids, and amino acids. The study showed that ripening was characterized by starch degradation and increasing soluble solids, while differences among cultivars indicated that genetic background can influence the metabolic characteristics and progression of banana ripening.

Materials and methods

Variables

Accumulated weight loss

Weight loss during storage is an indicator commonly used to evaluate physical changes in fruits during the postharvest period. Siebeneichler et al. (2020) evaluated this variable by periodically weighing the fruits during storage and expressing the results as a percentage of weight loss. In the present study, the main response variable was weight loss, expressed as a percentage of initial weight. Weight loss was calculated as the percentage reduction relative to the initial weight recorded at day 0.

$$\text{Weight loss (\%)} = \frac{W_0 - W_n}{W_0} \cdot 100$$

Where:

W_0 = initial weight.

W_n = weight at time n.

Days after harvest

Days after harvest were used as the time variable in the regression analysis.

Packaging type

No polyethylene bag, non-perforated polyethylene bag, and perforated polyethylene bags were considered as a descriptive grouping variable to explore differences in weight loss patterns among treatments. Non-perforated and perforated bags specifications are as follows: food-grade low density polyethylene bags with dimensions 40.25 inches width, 50.50 inches long and 0.0015 inches thick. Perforated bags had 8 circular perforations of diameter 12 mm, while non-perforated bags lacked perforations, as its name suggests.

Ripeness stage

Ripeness stage was evaluated using a 7-point visual scale adapted for banana peel color development (Von Loesecke ripening scale), where stage 1 corresponded to completely green fruit and stage 7 corresponded to overripe fruit with extensive brown spotting.

Intermediate stages represented progressive changes in peel coloration from green to yellow and the appearance of brown spots, reflecting increasing ripeness during storage.

- Stage 1: Fully unripe, completely green peel.
- Stage 2: Light green peel.
- Stage 3: Yellowish green peel.
- Stage 4: Dominant yellow, slightly green at the peduncle and tip.
- Stage 5: Full yellow peel.
- Stage 6: Fully ripe, completely edible.
- Stage 7: Overripe, yellow with many brown/black spots.

Experimental procedure

Banana bunches from the variety “Giant Cavendish” were harvested at commercial maturity from farm Los Ángeles, located in Pasaje, El Oro, Ecuador. Clusters from similar physiological age were selected to ensure uniformity in respiration and transpiration rate, and only defect-free samples were included.

Initial weight was recorded at harvest (day 0). Clusters were then randomly assigned to one of the three packaging treatments. All samples were stored under controlled environmental conditions at an average temperature of $24.5\text{ °C} \pm 2.8\text{ °C}$ at the facilities of Prieto Grupo Agrícola, located in Pasaje, El Oro, Ecuador. Relative humidity was not measured. Weight measurements were taken at 12 time points over a 27-day storage period. Twelve measurements were collected based on logistical constraints and operational availability. Weight loss was calculated as the percentage reduction relative to initial weight.

Data analysis

Linear regression analysis was used to characterize the relationship between weight loss and storage time for each treatment. The regression equation, coefficient of determination (R^2), and slope were obtained for each treatment to describe the rate of weight loss during storage.

The normality of the data was assessed using the Shapiro–Wilk test. The results indicated that the data followed a normal distribution ($p > 0.05$). Therefore, a parametric statistical method (ANOVA) was considered appropriate for subsequent comparisons between treatments. Statistical significance was established at a significance level of 5% ($p < 0.05$). All statistical analyses and figures were done with SPSS.

Results

Accumulated weight loss

After 27 days of harvest, T1 non-perforated polyethylene bags exhibited the lower accumulated weight loss in this study, 2.15%. T2, perforated polyethylene bags exhibited a slightly higher weight loss, 3.65%. T0, no bag exhibited a far greater weight loss, 17.33%.

Table 1. *Accumulated weight loss over a 27 days storage period.*

Days after harvest	T0 no bag	T1 non- perforated polyethylene bag	T2 perforated polyethylene bag
2	1.44%	0.16%	0.27%
5	2.50%	0.29%	0.41%
7	4.05%	0.53%	0.71%
9	4.88%	0.54%	0.71%
12	6.15%	0.76%	0.98%
14	7.50%	0.92%	1.17%
16	8.61%	1.00%	1.30%
19	10.07%	1.13%	1.50%
21	11.63%	1.27%	1.97%
23	13.91%	1.48%	2.67%
27	17.33%	2.15%	3.65%

Regression models

Banana weight loss increased approximately linearly throughout the evaluated storage period. When describing a relationship of the form $y = f(x)$, where the dependent variable corresponds to the percentage of weight loss and the independent variable to the days after harvest, the following functions were obtained:

- For T0 we have an equation of: $y = -0.63 + 0.61 \cdot x$, and a R^2 of 0.979.

- For T1 we have an equation of: $y = -0.06 + 0.07 \cdot x$, and a R^2 of 0.949.
- For T2 we have an equation of: $y = -0.32 + 0.12 \cdot x$, and a R^2 of 0.888.

In general terms, this suggests weight loss is linear and does not accelerate within the evaluated time period and under the conditions of this experiment.

The developed models may be used as predictive tools to estimate weight loss under storage conditions similar to those evaluated in this study. For instance, under conditions comparable to those of the present study, bananas packed in non-perforated bags and transported for 21 days would be expected to exhibit approximately 1.41% weight loss.

Figure 1

Weight loss dynamics for bananas stored in carton boxes with no polyethylene bags.

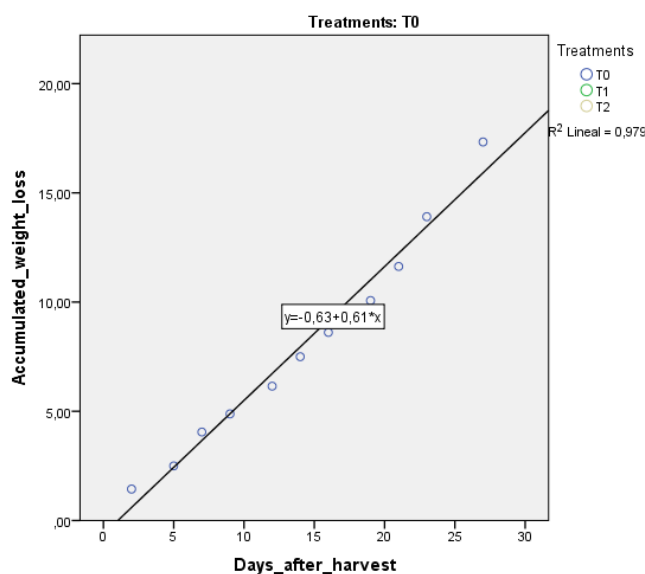


Figure 2

Weight loss dynamics for bananas stored in carton boxes with non-perforated polyethylene bags.

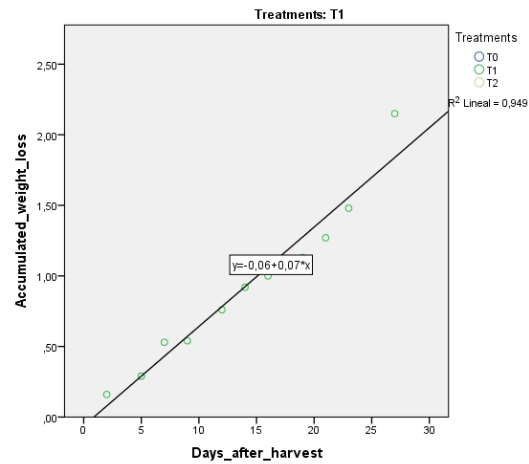


Figure 3

Weight loss dynamics for bananas stored in carton boxes with perforated polyethylene bags.

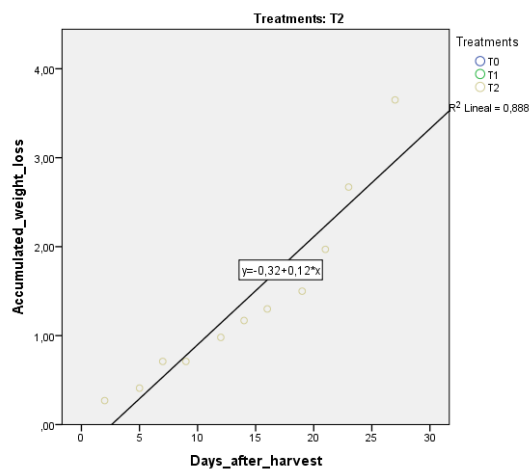
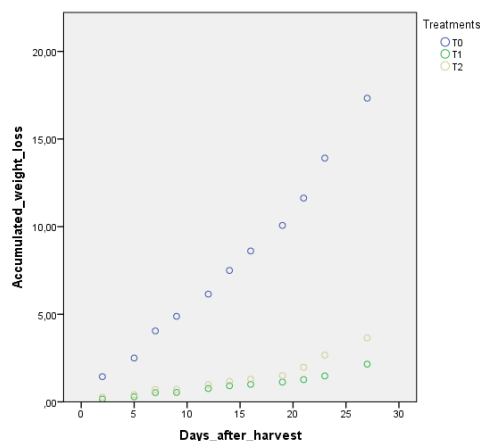


Figure 4

Comparative weight loss behavior of banana under different packaging systems.



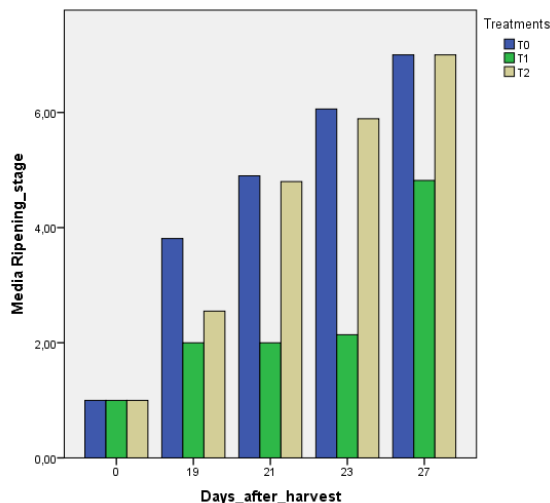
Ripeness stage

Ripeness progression for all treatments showed marked differences at day 19 after harvest, with T0 and T2 reaching stage 7 faster than T1. Despite accumulated weight loss in T1 and T2 being similar, T1 showed a lower rate of ripening progression at the 27 days mark.

Table 2. *Ripening stage at 0, 19, 21, 23 and 27 days after harvest.*

Days after harvest	T0 no bags	T1 non-perforated polyethylene bags	T2 perforated polyethylene bags
0	1,00	1,00	1,00
19	3,81	2,00	2,55
21	4,90	2,00	4,80
23	6,06	2,14	5,89
27	7,00	4,82	7,00

Figure 4. Comparative ripening behavior of banana under different packaging systems.



Statistical Analysis

Normality test

The normality of accumulated weight loss data was assessed using the Shapiro–Wilk test. The results indicated no significant departures from normality for T0 ($W = 0.925$, $p = 0.330$), T1 ($W = 0.951$, $p = 0.330$), or T2 ($W = 0.957$, $p = 0.785$).

Normality test

	Treatments	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
		Estadístico	gl	Sig.	Estadístico	gl	Sig.
Accumulated_weight_loss	T0	,160	12	,200*	,925	12	,330
	T1	,092	22	,200*	,951	22	,330
	T2	,184	8	,200*	,957	8	,785

*. Esto es un límite inferior de la significación verdadera.

a. Corrección de significación de Lilliefors

ANOVA

Accumulated weight loss differed considerably among the three packaging treatments. The mean accumulated weight loss at day 27 after harvest was 17.33% for T0 (without polyethylene bag), 2.15% for T1 (non-perforated polyethylene bag), and 3.65% for T2 (perforated

polyethylene bag). The standard deviations were 1.33%, 0.24%, and 0.37%, respectively, for T0, T1, and T2.

Levene's test indicated that the assumption of homogeneity of variances was not satisfied ($F(2,39) = 20.557$, $p < 0.001$). Therefore, the Games–Howell post hoc test was used for pairwise comparisons. The one-way ANOVA indicated significant differences in accumulated weight loss among treatments ($F(2,39) = 1683.564$, $p < 0.001$).

The Games–Howell analysis showed significant differences between all treatment pairs. T0 exhibited significantly greater accumulated weight loss than T1 (mean difference = 15.17 percentage points, $p < 0.001$) and T2 (mean difference = 13.68 percentage points, $p < 0.001$). In addition, T2 showed significantly greater accumulated weight loss than T1 (mean difference = 1.50 percentage points, $p < 0.001$). Thus, the observed ranking of treatments according to accumulated weight loss was $T0 > T2 > T1$, with T1 showing the lowest accumulated weight loss.

Descriptivos

Accumulated weight loss

	N	Media	Desviación estándar	Error estándar	95% del intervalo de confianza para la media		Mínimo	Máximo
					Límite inferior	Límite superior		
T0	12	,173256	,0133473	,0038530	,164775	,181736	,1477	,1888
T1	22	,021507	,0024427	,0005208	,020424	,022590	,0167	,0253
T2	8	,036487	,0037354	,0013207	,033364	,039610	,0304	,0425
Total	42	,067717	,0681862	,0105214	,046469	,088965	,0167	,1888

Prueba de homogeneidad de varianzas

Accumulated weight loss

Estadístico de Levene	gl1	gl2	Sig.
20,557	2	39	,000

ANOVA

Accumulated weight loss

	Suma de cuadrados	gl	Media cuadrática	F	Sig.
Entre grupos	,188	2	,094	1683,564	,000
Dentro de grupos	,002	39	,000		
Total	,191	41			

POSTHOC**Comparaciones múltiples**

Variable dependiente: Accumulated_weight_loss

Games-Howell

(I) Treatments	(J) Treatments	Diferencia de medias (I-J)	Error estándar	Sig.	Intervalo de confianza al 95%	
					Límite inferior	Límite superior
T0	T1	,1517487*	,0038881	,000	,141302	,162195
	T2	,1367683*	,0040731	,000	,126057	,147479
T1	T0	-,1517487*	,0038881	,000	-,162195	-,141302
	T2	-,0149804*	,0014197	,000	-,018923	-,011038
T2	T0	-,1367683*	,0040731	,000	-,147479	-,126057
	T1	,0149804*	,0014197	,000	,011038	,018923

*. La diferencia de medias es significativa en el nivel 0.05.

Weight loss in bananas seems to be primarily associated with water loss through transpiration. Packaging creates a modified microenvironment around the fruit by reducing vapor exchange with the surrounding atmosphere, thus decreasing transpiration rates. The lower weight loss observed in T1 may therefore be attributed to the greater restriction of water vapor produced by the non-perforated bags. In contrast, perforations in T2 and the absence of bagging in T0 likely allowed greater gas and moisture exchange with the environment, explaining the slightly higher and substantially higher losses when compared with T1.

The regression models developed for each treatment showed high coefficients of determination (R^2 values ranging from 0.888 to 0.979), indicating that weight loss followed a nearly linear trend during the evaluated period. The linear increase suggests that under the storage conditions of this study, weight loss occurred at a relatively constant rate.

The observed reduction in weight loss in packaged fruit agrees with Hailu et al. (2014), Pérez (2014), Woldetsadik et al. (2015), Ahmad et al. (2006) and Zerga (2020), who reported improved moisture retention and shelf-life extension in bananas packed with polyethylene bags.

The ripening observations suggest that weight loss is not influenced by ripening progression, and that both are independent to each other. T1 and T2 had very similar weight loss patterns but the ripening progression differed.

The Shapiro–Wilk results did not indicate significant departures from normality for any of the three treatments: T0 ($W = 0.925$, $p = 0.330$), T1 ($W = 0.951$, $p = 0.330$), and T2 ($W = 0.957$, $p = 0.785$). Because all p -values were greater than 0.05, there was insufficient evidence to reject the assumption of normality for the accumulated weight-loss observations. These results supported the use of a parametric comparison as a descriptive statistical procedure.

The one-way ANOVA detected a statistically significant difference among the treatment means ($F(2,39) = 1683.564$, $p < 0.001$). The Games–Howell results indicated significant differences between each pair of treatments ($p < 0.001$). The mean differences were 15.17 percentage points between T0 and T1, 13.68 percentage points between T0 and T2, and 1.50 percentage points between T1 and T2. These statistical results are consistent with the descriptive pattern observed at day 27, in which T0 presented the highest accumulated weight loss, followed by T2 and T1.

Taken together, the descriptive results, regression models, and statistical comparisons consistently indicate a strong difference in weight-loss behavior between unpackaged and polyethylene-packaged bananas.

Conclusions

The use of polyethylene bag packaging substantially reduced postharvest weight loss in bananas during the evaluated storage period. Non-perforated polyethylene bags (T1) exhibited the lowest accumulated weight loss (2.15%), followed by perforated polyethylene bags (T2) (3.65%), while bananas stored without bags (T0) showed considerably greater losses (17.33%).

Weight loss increased approximately linearly throughout storage under all evaluated treatments, with high coefficients of determination ($R^2 = 0.888\text{--}0.979$), indicating a relatively constant rate of weight loss during the study period. The developed regression equations may serve as practical predictive tools for estimating weight loss under storage conditions similar to those evaluated in this experiment.

The additional evaluation of ripening progression provided complementary information for interpreting the observed weight-loss behavior. Although differences in ripening progression were observed among treatments, the relatively similar weight-loss patterns in T1 and T2 suggest that ripening stage alone doesn't not fully account for postharvest weight-loss dynamics under the evaluated conditions.

The statistical analysis indicated differences among the three treatments (one-way ANOVA, $F(2,39) = 1683.564$, $p < 0.001$). Because the variances were unequal (Levene's test, $p < 0.001$), Games–Howell comparisons were used and indicated differences between each pair of treatments ($p < 0.001$). Games–Howell post hoc comparisons indicated significant differences between all treatment pairs ($p < 0.001$). The mean accumulated weight loss was higher in T0 than in T1 and T2 by 15.18 and 13.68 percentage points, respectively, while T2 showed 1.50 percentage points greater weight loss than T1.

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