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Comparative analysis of different packaging materials on the postharvest performance of banana fruits

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Abstract
An experiment was carried out to investigate the comparative analysis of different packaging materials on the postharvest performance of banana fruit. A laboratory experiment was laid out at Gokuleshwor Agriculture and animal science college in the month of March 2023. The experiment was conducted in a complete random design (CRD) with 5 treatments and 4 replications. The treatments were t1: control, t2: banana leaf, t3: straw, t4: polythene bag, t5: card box. The highest physiological weight loss (27.677 gm) was recorded at the control (unpackaged) whereas the lowest weight loss (12.61 gm) was recorded from the polythene bag. The maximum value of TSS was recorded on fruits treated in a polyethylene bag (15.325 ˚Brix) whereas the minimum value of TSS was recorded in the control (12.725 ˚Brix). Titrable acidity was found to be highest in polythene bags (0.318) and lowest in cardboard and control (0.2437), titrable acidity decreasing as the ripening advances. Pulp firmness shows a decreasing pattern. The changes were observed faster in control all day, and a slower decrease in pulp firmness was observed in the polythene bag. As ripening advances banana pulp thickness shows an increased trend over the storage period. In 16 days higher pulp thickness was found in the control (2.78 cm), whereas lower pulp thickness was found in the polythene bag (2.70 cm). As seeing the overall trend, the pulp thickness seems to be increased with time. As ripening advances banana peel thickness shows the decreased trend over the storage period. In 16 days higher peel thickness was found in polythene (0.444 cm) whereas lower peel thickness was found in the control (0.41 cm). Therefore, it is clear that banana fruits packaged in polythene bags demonstrated remarkable quality and shelf life when compared to alternative packaging materials.

Keywords: Banana, shelf life, packaging materials, effect

Introduction
The banana (*Musa* × *paradisiaca*) is an important tropical fruit native to southeast Africa. The banana's popularity is also attributed to its versatility in various cuisines, where it is enjoyed in desserts, smoothies, and even savory dishes, and its name comes from the Arabic word 'banana', which means finger. A Banana is a large perennial herb with leaf sheaths that form a trunk-like pseudo stem. They vary in height ranges from 1.5-8 m and generally divide into a starchy type called plantation and a desert type known as banana (Hailu *et al*, 2014) [57]. The fruit is grown in more than 100 countries throughout the tropics and subtropics with an annual production of about 98 million tons. (Frison and Sharrock, 1999) [16]. It is an early maturing, fast-growing herbaceous and perennial herb of about 2 to 9 meters in height. Banana is a climacteric fruit that shows an increase in respiration resulting in color, flavor, aroma, and texture change (Sogo-Temi, Idowu, and Idowu, 2014) [58]. The principal countries in terms of production are Brazil, India, and the Philippines (Maduwanthi and Marapana, 2019) [35]. Since history banana has been a staple human food. After rice, wheat, and maize, bananas are ranked as the world's fourth-largest food crop (Hailu *et al.*, 2013) [59]. It is usually eaten raw when ripe and is a major starchy food common in Sub-Sahara Africa and Asia, providing more than 25% of carbohydrates (Adeniji *et al*, 2007) [1]. Bananas are uniquely remarkable for their high calories and nutritive value, playing a significant role in the human diet by providing essential vitamins, minerals, and dietary fiber (Khader *et al.*, 1990) [30]. Banana contains nearly all the essential nutrients including minerals and vitamins and has several medicinal properties (Bose, 1990) [7].

In addition to health benefits, most people enjoy eating bananas. It can be eaten alone or in combination with fruit salad, added to the jelly, or made into a milkshake or smoothie. Banana is one of the most affordable fruits in the marketplace with yearly availability in almost all parts of the world Bananas are broadly classified into dessert and cooking types (Nayar, 2010) [36]. It has a number of importance in different fields like in medicines, cosmetics, and agro-based industries for processing. Raw, ripen and processed bananas are used for various items. Not only fruit but other also parts of banana have a variety of uses, its leaves are used in religious ceremonies as well as can be used as packaging material. The stems and leaves of bananas can serve as valuable livestock feed, expanding their usefulness beyond just their fruit. Banana fibers are used to make clothes, tissue paper, cardboard, paper, etc. Banana is one of the major fruit of Nepal in terms of social and economic aspect.

It occupied an area of 5732 hectares with a total productive area is 3742 hectares, which Produces approximately 53257 metric of fruits (MOAC 2007) [42]. Among the major fruit crop growing in Nepal banana stands in 4th position after citrus, mango, and apple (K.C., Gautam and Tiwari, 2014) [27]. The B/C ratio of bananas was 2.35, which was better as examine to different staple crops (MOAD, 2014) [40]. In the Nepalese geophysical situation, it can be grown from Terai to 1500 maltitude of mid-hills, where frost does not occur usually (Gautam and Dhakal 1991) [19]. The major production areas are Terai, valleys, and river basins (Bhusal *et al*. 2008) [6]. The most common variety cultivated in Nepal is G9 and Malbhog. According to ICIMOD banana is a high-value agricultural product and a major fruit in Nepal in terms of the potential growing area, production, and domestic consumption (ICIMOD, 2015) [23]. It is currently grown in 68 districts, and the total productive area of banana plantations in 2012/2013 was 11,864 ha, with a total production of about 182,005 tons (Phulara *et al*., 2020) [37]. Banana ripening is the result of transcriptional regulation (Yan *et al*., 2019) [55], associated with an increase in the respiration rate and autocatalytic synthesis of ethylene (Johnson *et al*., 1997; Gamage & Rehman, 1999) [26, 17]. The action of ethylene results in fruit softening, accelerating deterioration, and shortening postharvest shelf-life. The climacteric peak triggers various physiological and physicochemical changes: conversion of starch to sugars (Hill &Ress, 1995) [21], enzymatic degradation of the structural carbohydrates (Kojima *et al*., 1994) [32], and degradation of the chlorophyll (Thomas & Janave, 1992) [52] which changes the color by uncovering the carotenoids in fruit peel and by regulating the pigment change. During the ripening period, the propensity of decreasing unsaturated fatty acids and the small upsurge of saturated fatty acid concentration was perceived (Palmer, 1971) [46]. These changes affect the organoleptic attributes of the fruit as well as commercial value and need to be controlled to minimize losses (Liu *et al*., 2013) [34]. In nature, banana ripens easily showing changes in skin color, flavor, and texture of the flesh during ripening (Botondi *et al*., 2014) [8]. But natural ripening may result in softening with non-uniform, dull, pale yellow, and unattractive colors (Eduardo, 2012) [13]. Besides, due to slow ripening natural process leads to high weight loss, splitting fruit's peel (Subbaiah *et al*., 2013) [51]. To overcome these disputes small and large-scale farmers use ripening agents. Being climacteric fruit, it is usually harvested at the pre-climacteric stage and for commercial purposes, it is artificially ripened by using different ripening agents. Artificial ripening techniques enable traders to optimize transportation efficiency by minimizing losses and ensuring the product reaches the desired ripening stage at the right time. Banana ripening depends on internal factors such as ethylene production or sensitivity, respiration, and market requirements. Though the acidity as well as sweetness rises during ripening the fruit still tastes sweeter (Rahman *et al*., 2008) [47]. Once harvested it is highly perishable, with short shelf life leading to high postharvest losses of about 20-50% due to poor handling and quality deterioration (Ajayi and Mbah, 2007; Zewter *et al*., 2012) [3, 60]. Bananas are usually harvested at the green stage to avoid postharvest losses so are artificially ripened using the ripening agent. These include ethylene gas, Ethephon, ethylene glycol, ethrel, and calcium carbide (Singal *et al*., 2011) [29]. Thus, in this study, we aimed to assess the comparative analysis of different packaging materials on the postharvest performance of banana fruits.

Materials and Methods

Description of the experimental site

Laboratory experiments were carried out at Gokuleshwor Agriculture and Animal Science College. It is located in the Baitadi district of Nepal, which is 811 meters above sea level and is geographically 29˚40' North latitude and 80˚34' East longitude. The average annual temperature of this zone is 22.87 °C and the average annual rainfall is 1037mm.

Experimental materials

Banana fruit (Grand naine) was harvested at the physiological maturity stage with uniform size, shape, and color and was collected from "easy farming" Dhangadi. The fruits were transported to the experimental site one day after harvest. Different locally available packaging materials were used as treatment.

Description of the treatment

T_1: Control (No packaging)
T_2: Banana leaf
T_3: Rice straw
T_4: Polythene bag
T_5: Cardboard box

Experimental setup

The laboratory experiment was conducted from March 12, 2023, to March 28, 2023, in the Gokuleshwor Agriculture and animal science college horticulture laboratory. The design of the experiment was a complete random design (CRD) with 5 treatments and 4 replications carried out. The different locally available packaging materials are banana leaf, rice straw, polythene bag, cardboard box, and open-air as a control. There were a total 20 number of the plots made each plot containing 24 fingers of banana.

Data collection

Data were collected from banana fruit of different packaging materials at three days intervals. The observation recorded in this project was:

Physiological weight loss (gram): % Weight loss = (Initial weight – Final Weight)/Initial Weight * 100

Firmness (kg/cm^2): Measured with the help of a penetrometer
Total soluble solid (˚Brix): Measured by hand-held refractometer
Titrable acidity (gm/lit): Total titrable acidity (g/L) = Amount of NAOH required to titrate * 0.75
Peel thickness (cm): Measured with Vernier caliper
Pulp thickness (cm): Measured with a Vernier caliper

Statistical Analysis
The collected data were entered in Excel 2016 and subjected to Analysis of Variance (ANOVA) by using GenStat. Fisher's Least Significance Difference (LSD) was used to establish the multiple comparisons of mean values. Mean values were considered at a 5% significance level (p< 0.05).

Results and Discussion
Effect of packaging materials on Physiological Weight Loss: The effect of ripening agents on the ripening of bananas was found to be highly significant on all days. Total weight loss of both treated and untreated bananas increases with the advancement of storage. This increase in PWL of Ethephon-treated bananas could be due to an upsurge in respiration rate that leads to faster ripening compare to other treatments. Similar results were reported by Singh *et al*., (1977) [61]. The Physiological weight loss on day 4 was found highest in the control (6.19) while the lowest physiological weight Loss was seen on the Treatment polythene bag (0.479). Till 16 days the total physiological weight loss was found highest in control (21.67) and lowest was found in a polythene bag (12.61). The highest weight loss was found in control and the lowest weight loss was found in polythene bags all days, which is due to transpiration and respiration process. Weight loss of fresh fruits is primarily due to transpiration and respiration (Tadesse, 1991) [62].

Table 1: Effect of packaging materials on Physiological Weight loss (gram)

Treatments	Day 4	Day 8	Day 12	Day 16
Control	6.19^a	11.945^a	17.86^a	27.67^a
Banana Leaf	2.79^b	7.11^b	14.6^b	23.31^b
Straw	2.342^c	6.53^c	14.4^b	21.97^c
Polythene	0.497^e	2.96^e	8.05^d	12.61^e
Cardboard	1.63^d	5.74^d	11.65^c	16.20^d
F test	***	***	***	***
LSD Value	0.241	0.576	0.93	1.279
CV%	5.955	5.573	4.634	4.170
Sem±	0.080	0.19	0.309	0.424
Grand Mean	2.69	6.86	13.32	20.353

Significant traits are denoted * for p<0.05, ** for p<0.01, and p<0.001 and NS for non-significant

Effect of packaging materials on Total Soluble Solid (TSS): The ripening agents show a significant variation in the total soluble solid of the banana. There was a rapid increase in TSS till 13 days after then decreased. On days 7, 10, 13, and 16 days the highest TSS was obtained by treatment polythene bag, whereas the minimum TSS value was obtained from control on all days The increase in TSS might have resulted from an increase in the concentration of organic solutes as a consequence of water loss and hydrolysis of starch into soluble sugar as sucrose, fructose, and glucose (Awoke *et al*. 2012) [63]

Table 2: Effect of packaging materials on total soluble solid (˚Brix)

Treatments	Day 1	Day 4	Day 7	Day 10	Day 13	Day 16
Control	5.25^a	6.47^a	7.90^c	10.02^c	13.55^c	12.725^c
Banana Leaf	5.30^a	6.50^a	7.95^{bc}	10.27^{bc}	14.62^b	13.725^b
Straw	5.22^a	6.52^a	8.00^{bc}	10.27^{bc}	14.63^b	13.45^{bc}
Polythene	5.22^a	6.35^b	8.22^a	10.60^a	16.03^a	15.325^a
Cardboard	5.27^a	6.42^a	8.05^b	10.35^{ab}	15.10^b	14.05^b
F test	NS	NS	**	**	***	***
LSD	0.152	0.13	0.139	0.262	0.52	0.505
CV%	1.92	1.34	1.149	1.685	2.312	2.417
Sem±	0.05	0.043	0.046	0.087	0.17	0.167
Grand Mean	5.25	6.45	8.025	10.31	14.79	13.85

Significant traits are denoted * for p<0.05, ** for p<0.01, and p<0.001 and NS for non-significant

Effect of packaging materials on Titrable Acidity (TA)
The effect of the ripening agent on titrable acidity was found in non-significant on all days. TA tends to increase at the initial stage but subsequently decreases with the increment in storage time. On day 1 the change was seen highest on straw (0.488), and lowest in control (0.43). Titrable acidity decreased on day 16, highest found in polythene bags (0.318) and lowest in cardboard and control (0.2437). Hence titrable acidity decreasing as the ripening advances.

Table 3: Effect of packaging materials on titrable acidity (g/L) of banana

Treatments	Day 1	Day 4	Day 7	Day 10	Day 13	Day 16
Control	0.43^a	0.487^a	0.45^a	0.412^a	0.338^a	0.2437^a
Banana Leaf	0.45^a	0.488^a	0.468^a	0.412^a	0.337^a	0.2625^a
Straw	0.488^a	0.487^a	0.469^a	0.43^a	0.356^a	0.281^a
Polythene	0.487^a	0.487^a	0.45^a	0.413^a	0.375^a	0.3187^a
Cardboard	0.487^a	0.506^a	0.469^a	0.413^a	0.32^a	0.2437^a
F-test	NS	NS	NS	NS	NS	NS
LSD	0.07	0.064	0.06	0.064	0.0799	0.0583
CV%	9.906	8.59	8.655	10.14	15.37	14.344
Sem±	0.023	0.02	0.02	0.021	0.026	0.019
Grand Mean	0.469	0.49	0.46	0.416	0.345	0.27

Significant traits are denoted * for p<0.05, ** for p<0.01, and p<0.001 and NS for non-significant

Effect of packaging materials on Pulp firmness (Kg/cm^3)
The effect of ripening agents on pulp firmness was found to be significant. As ripening advances banana pulp firmness shows a decreasing pattern. The changes were observed faster on control all days, and a slower decrease in pulp firmness was observed in the polythene bag. Loss of firmness or softening during ripening has been linked to the breakdown of starch into sugars, breakdown of cell walls, or reduction in the cohesion of the middle lamella due to solubilization of pectic substances (Palmer 1971) [46].

Table 4: Effect of packaging materials on Pulp firmness (Kg/cm^3) of Banana

Treatments	Day 1	Day 4	Day 7	Day 10	Day 13	Day 16
Control	9.12^a	8.645^b	8.107^a	7.22^a	5.13^c	2.07^c
Banana Leaf	9.36^a	9.153^a	8.529^a	7.43^a	5.73^b	2.143^c
Straw	9.30^a	8.922^{ab}	8.386^a	7.46^a	6.44^a	3.01^b
Polythene	9.385^a	9.207^a	8.595^a	7.57^a	6.74^a	3.34^a
Cardboard	9.285^a	9.017^{ab}	8.365^{ab}	7.34^a	5.975^a	2.235^c
F test	NA	*	NA	NA	***	***
LSD	0.26	0.369	0.356	0.347	0.37	0.256
CV%	1.85	2.724	2.816	3.11	4.083	6.641
Sem±	0.08	0.123	0.118	0.115	0.123	0.085
Grand Mean	9.29	8.989	8.397	7.404	6.003	2.56

Significant traits are denoted * for $p<0.05$, ** for $p<0.01$, and $p<0.001$ and NS for non-significant

Effect of packaging materials on pulp thickness

The effect of ripening agents on pulp thickness was found to be non-significant. As ripening advances banana pulp thickness shows an increased trend over the storage period. On 16 days higher pulp thickness was found in the control (2.78 cm), whereas lower pulp thickness was found in the polythene bag (2.70 cm). As seeing the overall trend, the pulp thickness seems to be increased with time.

Table 5: Effect of packaging materials on Pulp Thickness (cm) of Banana

Treatments	Day 1	Day 4	Day 7	Day 10	Day 13	Day 16
Control	2.66^a	2.667^a	2.71^a	2.737^a	2.77^a	2.78^a
Banana Leaf	2.66^a	2.665^a	2.68^a	2.697^a	2.745^a	2.76^a
Straw	2.64^a	2.64^a	2.66^a	2.68^a	2.7^a	2.72^a
Polythene	2.66^a	2.67^a	2.675^a	2.68^a	2.69^a	2.70^a
Cardboard	2.65^a	2.66^a	2.677^a	2.69^a	2.69^a	2.71^a
F-test	NS	NS	NS	NS	NS	NS
LSD	0.219	0.211	0.193	0.19	0.192	0.19
CV%	5.48	5.42	4.78	4.68	4.674	4.61
Sem±	0.07	0.07	0.064	0.063	0.064	0.063
Grand Mean	2.655	2.6585	2.681	2.698	2.72	2.73

Significant traits are denoted * for $p<0.05$, ** for $p<0.01$, and $p<0.001$ and NS for non-significant

Table 6: Effect of packaging materials on peel thickness

Treatments	Day 1	Day 4	Day 7	Day 10	Day 13	Day 16
Control	0.45^a	0.45^a	0.45^a	0.443^a	0.435^a	0.408^b
Banana Leaf	0.45^a	0.45^a	0.45^a	0.445^a	0.434^a	0.428^{ab}
Straw	0.46^a	0.45^a	0.45^a	0.449^a	0.445^a	0.439^{ab}
Polythene	0.45^a	0.45^a	0.45^a	0.449^a	0.446^a	0.444^a
Carboard	0.45^a	0.45^a	0.45^a	0.45^a	0.447^a	0.4437^a
F-Test	NS	NS	NS	NS	NS	NS
LSD	0.033	0.034	0.335	0.034	0.036	0.031
CV%	4.832	4.93	4.92	5.02	5.423	4.752
Sem±	0.011	0.01	0.011	0.011	0.012	0.01
Grand Mean	0.455	0.45	0.451	0.45	0.44	0.433

Significant traits are denoted * for $p<0.05$, ** for $p<0.01$, and $p<0.001$ and NS for non-significant

Effect of packaging materials on peel thickness

The effect of ripening agents on peel thickness was found to be non-significant. As ripening advances banana peel thickness shows the decreased trend over the storage period. On 16 days higher peel thickness was found in polythene (0.444 cm) whereas lower peel thickness was found in the control (0.41 cm). As seeing the overall trend, the peel thickness seems to be decreased with time.

Conclusion

The experiment conducted at Gokuleshwor Agriculture and Animal Science College in March 2023 aimed to investigate the effect of different packaging materials on the shelf life and quality of banana fruits. The experiment was designed with five treatments and four replications, using complete random design (CRD). The treatments included a control (unpackaged), banana leaf, straw, polythene bag, and cardboard box. Throughout the storage period, the banana fruits packaged in polythene bags exhibited the most favorable results in terms of weight loss, total soluble solids (TSS), titrable acidity, pulp firmness, pulp thickness, and peel thickness. The polythene bag packaging significantly reduced physiological weight loss compared to the other treatments, while also maintaining higher TSS values, indicating better fruit sweetness. Additionally, the polythene bags helped preserve the firmness of the banana pulp for a longer duration compared to other materials, resulting in a slower rate of pulp softening. Furthermore, as ripening progressed, the pulp thickness of bananas in the polythene bags showed a consistent increasing trend, indicating better preservation of fruit texture. On the other hand, the peel thickness of bananas in polythene bags exhibited a decreasing trend over the storage period, which might be attributed to better gas exchange and regulation of ethylene levels, thereby slowing down the ripening process. The results suggest that polythene bag packaging demonstrated remarkable benefits for maintaining the quality and extending the shelf life of banana fruits compared to alternative packaging materials such as banana leaf, straw, and cardboard box. This finding has practical implications for the banana industry and can be utilized by producers and suppliers to enhance the post-harvest handling and marketing of bananas, ultimately leading to reduced losses and improved fruit quality for consumers. However, further research and trials may be necessary to explore the environmental impact and feasibility of using polythene bags as a long-term packaging solution for bananas.

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