


## Effect of Wrapping Materials and Maturity Stages on Postharvest Loss Reduction of Papaya

Sujan Subedi<sup>1</sup>\*, Giri Dhari Subedi<sup>2</sup>, Dipendra Ghimire<sup>1</sup>, Ishwori Prasad Gautam<sup>1</sup>, Suvechchha Khanal<sup>1</sup>, Purushottam Prasad Khatiwoda<sup>3</sup> and Sanjeeb Thapa<sup>4</sup>

<sup>1</sup>National Horticulture Research Centre, Khumaltar, Lalitpur, Nepal @suzsubedi@gmail.com;

 <https://orcid.org/0000-0003-0470-5297>; DG: [ghimiredipendra44@gmail.com](mailto:ghimiredipendra44@gmail.com); IPG, [ishworigautam@gmail.com](mailto:ishworigautam@gmail.com); SK: [shuvechchhak@gmail.com](mailto:shuvechchhak@gmail.com);

<sup>2</sup>National Potato Research Program, Khumaltar, Lalitpur, Nepal: GDS: [subedigiridharinarc@gmail.com](mailto:subedigiridharinarc@gmail.com);

<sup>3</sup>Value Chain Development Project, Lalitpur, Nepal: PPK: [purushottam.khathiwada@vcdp.org.np](mailto:purushottam.khathiwada@vcdp.org.np);

<sup>4</sup>Banaras Hindu University, Varanasi, Uttar Pradesh, India: ST: [sanjeebthapa331@gmail.com](mailto:sanjeebthapa331@gmail.com)

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### ABSTRACT

Papaya fruits are vulnerable to high postharvest losses if harvesting and handling techniques are inappropriate. Therefore, an experiment was conducted in two consecutive years, 2019 and 2020, to assess the effects of wrapping materials and maturity stages on postharvest loss reduction of papaya stored at ambient condition. A factorial combination of four wrapping materials (brown paper, white paper, fiber bag, and control) and three maturity stages (MS2; few yellow streaks from base to stalk end of fruits, MS3; 1/2 ripe, and MS4; 3/4 ripe), using a completely randomized design (CRD) with three replications was used to carry out this experiment. The papaya fruits were evaluated for transportation weight loss, bruised fruit percent, physiological weight loss, decay percent, total soluble solids, firmness, and shelf life. The result revealed that wrapping materials significantly affected on the transportation weight loss, percent bruised fruit, decay percent, and shelf life. The stage of maturity had a significant effect on TSS and firmness of the fruit. However, the interaction of wrapping materials and maturity stages had a non-significant effect on all the parameters. Out of the four wrapping materials, brown paper wrapped fruits had the lowest bruised fruit (4.1%), the lowest decay (10.8%), and the highest shelf life (11.8 days), while MS2 showed the minimum bruised fruit (15.1%), decay (21.2%), and shelf life (12.8 days). Fruit harvested at MS2 wrapped with brown paper can reduce postharvest loss and improve shelf life of papaya.

**Keywords:** firmness, shelf life, total soluble solid, weight loss

### सारांश

मेवाको फललाई राम्रोसंग ओसारपसार नगरेमा उत्पादनोपरान्त क्षति धेरै हुने गर्दछ। तसर्थ मेवाको उत्पादनोपरान्त क्षति न्यूनीकरण गर्ने उद्देश्यले मेवाको परिपक्व अवस्था र प्याकेजिंगका विभिन्न विधिहरू अपनाएर एक परीक्षण संचालन गरिएको थियो। उक्त परीक्षणमा परिपक्व अवस्थाका तीन र प्याकेजिंगका चार भिन्न भिन्न विधिहरूलाई सि.आर.डी.मा तीन रेप्लिकेशनमा गरिएको थियो। यस परीक्षणमा दुवानी गर्दा हुने तौल ह्रास, चोट लागेका फल, भण्डारणमा हुने तौल ह्रास, सडेका फल, कुल घुलनशिल ठोस पदार्थ, फलको कडापन र भण्डारण आयुको मूल्यांकन गरिएको थियो। उक्त परीक्षणको नतिजा अनुसार प्याकेजिंगका विभिन्न विधिहरूले दुवानी गर्दा हुने तौल ह्रास, दुवानी गर्दा चोट लागेका फल, सडेको फल र भण्डारण आयुमा उल्लेखनीय असर गरेको देखियो भने मेवाको परिपक्व अवस्थाले पनि दुवानी गर्दा तौल ह्रास, चोट लागेका फल, सडेको फल, भण्डारण आयुको अलवा फलको कडापन र कुल घुलनशिल ठोस पदार्थमा पनि असर गरेको भेटियो। तर परिपक्व अवस्था र प्याकेजिंगको अन्तरक्रियाले लगभग सबै गणहरूमा खासै असर गरेको देखिएन। प्याकेजिंगका विधिहरूमध्ये खैरो कागजले प्याकिंग गर्दा अरुमा भन्दा दुवानीमा चोट लागेका कम फल (४.१%), कम सडेका फल (१०.८%) र बढी भण्डारण आयु (११.८ दिन) देखियो। त्यसैगरी मेवाको परिपक्व अवस्था मध्ये परिपक्व अवस्था २ भएका फलहरूको दुवानी गर्दा चोट लागेका कम फल (१५.१%), कम सडेका फल (२१.२%) र बढी भण्डारण आयु (१२.८ दिन) पाइयो। यी दुई विधिहरूलाई फरक फरक तरिकाले प्रयोग गर्दा मेवाको भण्डारण अवधि र उत्पादनोपरान्त क्षति न्यूनीकरण गर्न सकिने हुँदा यो प्रविधिहरूलाई मेवाको उत्पादनोपरान्त क्षति न्यूनीकरण गर्नको लागि सिफारिस गर्न सकिन्छ।

## **INTRODUCTION**

Papaya is a widely cultivated and economically important delicious fruit belonging to the Caricaceae family (Samson 1986). Papaya is cultivated throughout the tropical and subtropical countries for its fruits which can be consumed both fresh and as a processed product (Chonhenchob and Singh 2005). Papaya is believed to be originated from southern Mexico and neighboring Central America. The Worldwide papaya productive area, production, and productivity was 468731 hectares, 13.89 million tons, and 29.6 ton/ha respectively (FAOSTAT 2020). India has the highest papaya production in the world (5.9 billion ton) whereas Nepal is in 30<sup>th</sup> position (FAOSTAT 2020). The total papaya cultivated area was 1,382 ha, production was 18,310 ton and productivity was 13.3 ton/ha in Nepal (MoALD 2020). Papaya is a wholesome fruit that contains 85-90% water, 10-13% sugar, 0.6% protein as well as vitamin A, C, B, B<sub>2</sub>, iron, calcium, and phosphorous (Workneh et al 2012). Papain extracted from the latex of unripe fruit is used as a meat tenderizer and for medical and industrial purposes (Salunkhe and Kadam 2014).

Papaya is highly perishable to postharvest losses because of high water content and softness of fruits during ripening. According to Paull and Chen (2011), mechanical injury during harvesting and transportation, chilling injury, and postharvest disease are the reasons of heavy postharvest loss in papaya. Similarly, harvesting stage, postharvest handling, packaging, mode of transportation, pre-treatment of fruits, and storage conditions affect the quality and marketability of papaya (Paull et al 1997). The major factors of postharvest loss in papaya were due to packaging, transportation and storage facilities (Kebede 1989). Total post-harvest loss of papaya fruit in Nepal was 17.9% among which about 5% losses were reported at collection, 7.1% from collection to wholesale market, and 5.8% from wholesale to retail market (VCDP 2018). The average wholesale price of papaya is high and is around Rs.60/kg due to higher postharvest loss in Nepal which is expensive as compared to India (KFVMD 2022).

Maturity stage is one of the most important factors affecting in papaya fruits. Fruits harvested at early stage tends to unripe completely while fruits harvested at over mature stage likely to damage and bruising during handling. Optimum harvesting stage one of the most determining factors for proper fruit ripening and retaining eating quality (Workneh et al 2012). In practice, color change is a maturity index for harvesting. Papaya fruits are generally harvested when the skin color changes from dark green to light green with one yellow streak appearing from the base to stalk end. Depending upon varieties and growing season, papaya fruits are normally harvested at color break stage (1/4 yellow) for export, and at 1/2 to 3/4 yellow for local markets (Kader 2006). However, in Nepal, papaya fruits are generally harvested at 3/4 (MS4) for distant market which results high postharvest loss and infected with diseases. So, it is necessary to identify appropriate harvesting stage of papaya for distant market and local market in order to reduce both qualitative and quantitative losses.

Packaging and wrapping of fruits is one of the most commonly used postharvest practices, adopted to protect produce from hazards of transportation and storage (Burdon 1997). Appropriate packaging, handling, and storage conditions have been used in developed countries for handling papaya fruits from farm to market to minimize quality degradation. Wrapping protects fruits from physical damage during transportation and marketing (Irtwange 2006). Packaging and wrapping have an important role to reduce damage, and protect the fruit from contamination and other physical disorders. Appropriate packaging and wrapping not only minimizes damage but also improves the papaya fruit quality. But in Nepal, instead of using plastic crates for transportation of wrapped fruits to distant and local markets, commercial farmers wrap the individual fruits with printed newspaper and directly pile the bulk volume of fruits into pickup vehicles. This practice ultimately reduces the quality of fruits by increasing bruising damages resulting higher postharvest losses. Jadhav et al (2021) reported that the printing ink present in the newspaper contains cancer-causing agents that can cause severe health issues. Despite the considerable postharvest loss at marketing stages between production and consumption, there has been few researches on papaya postharvest management in Nepal. Therefore, this investigation was conducted to identify suitable maturity stage and appropriate wrapping materials for reducing postharvest loss of papaya cv. Red Lady.

## **MATERIALS AND METHODS**

This experiment was conducted at the laboratory of National Horticulture Research Centre (NHRC), Khumaltar, Lalitpur in two consecutive years; 2019 and 2020 during November. A factorial combination of four wrapping materials (brown paper, white paper, fiber bag, and control; unwrapped fruits) and three stages of maturity viz. MS2; few yellow streaks from base to stalk end of fruits, MS3; 1/2 ripe, and MS4; 3/4 ripe were used at completely randomized design with three replications. Papaya fruits cv. Red Lady was harvested by hand picking from the farmer's field of Kalika Municipality, Tandi, Chitwan, Nepal. Visual maturity was determined as suggested by Basulto et al (2009). Uniform fruits size, color, and shape and free from defects were selected. Uniform size of papaya fruits from different maturity stages namely; MS2, MS3, and MS4 were harvested and were kept under shade for one hour to remove field heat. Then, the weight of individual ten fruits from each treatment was recorded followed by packaging with different wrapping materials i.e. fiber bag, brown paper, white paper, and control. The wrapped papaya fruits were kept in plastic crates (20 kg), loaded on the Bolero Pickup Van, and transported to NHRC Khumaltar, Lalitpur which was 165 km away from the farm. After transportation, the weight of fruits from each treatment was recorded to calculate the transportation weight loss. At the same time, numbers of bruised fruit were recorded and percentage was calculated. Fruits were stored at ambient conditions (16.4°C and 81% RH) for overnight. Following day, the experiment was set up to determine the shelf life of fruits. Six fruits from each treatment were kept to determine physiological weight loss (PWL) during storage. Similarly, four fruits from each treatment were further selected to determine TSS and firmness on 4<sup>th</sup> and 8<sup>th</sup> days after storage (DAS). The average temperature (16°C) and relative humidity (80%) of the storage room during research period (November) were recorded by using a Thermohygrometer. PWL (%) was recorded from the non-destructive sample on 4<sup>th</sup> and 8<sup>th</sup> DAS whereas decay (%) was calculated on the 8<sup>th</sup> DAS. TSS (°Brix) was determined from fruit pulp. Two drops of clear juices were placed on the prism of a digital handheld refractometer (Atago Model, Hybrid PAL-BXIACID F5, Japan). The firmness of the fruit was measured manually using a digital penetrometer (Lutron Model, FR-5120). Each fruit was dissected vertically, each half placed on a table with the cut area facing up, and the plunger vertically pressed into the flesh along the cut surface and firmness (kg/cm<sup>2</sup>) was recorded. The shelf life of fruits was recorded based on the appearance and spoilage of fruits by counting the marketable fruits until acceptable for marketing (Rao et al 2011). The statistical analysis was done by using GenStat (18<sup>th</sup> version, UK) and a comparison of the treatment means was made by Duncan Multiple Range Test (DMRT).

## **RESULTS**

### **Transportation weight loss**

The main and interaction effects of wrapping materials and maturity stages on transportation weight loss during the years was found to be non-significant (**Table 1**). However, 2019 and 2020, the main effects of wrapping materials was found to be highly significant with the highest transportation weight loss (2.1% and 2.3% respectively) in unwrapped fruits. The lowest transportation weight loss (1.7%) in 2019 was recorded in brown paper wrapped fruits which was statistically similar to white paper and fiber bag wrapped fruits. Similarly, in 2020 the lowest transportation weight loss (1.3%) was recorded in white paper wrapped fruits which was statistically similar to brown paper and fiber bag wrapped fruits.

### **Bruised fruits**

The effects of wrapping materials and maturity stages, and their interaction effects on bruised fruits (%) over the years and each year was found to be highly significant (**Table 1**). The bruised fruit (%) in control was 70.8% followed by fruits wrapped with fiber bag (8.3%), white paper (4.9%), and brown paper (4.2%). Similarly, the lowest bruised fruits (15.1%) was recorded in fruits harvested at MS2 and the highest bruised fruit (30.7%) was recorded in MS4.

**Table 1: Effect of wrapping materials and maturity stages on transportation weight loss (%) and bruised fruits (%) of papaya fruits during transportation from Kalika, Chitwan to Khumaltar, Lalitpur**

Treatment	Transportation weight loss (%)			Bruised fruits (%)		
	2019	2020	Mean	2019	2020	Mean
Wrapping materials (A)						
Brown paper	1.7 <sup>a</sup>	1.5 <sup>a</sup>	1.6	5.6 <sup>a</sup>	2.8 <sup>a</sup>	4.2 <sup>a</sup>
White paper	1.7 <sup>a</sup>	1.3 <sup>a</sup>	1.5	5.6 <sup>a</sup>	4.2 <sup>a</sup>	4.9 <sup>a</sup>
Fiber bag	1.8 <sup>a</sup>	1.4 <sup>a</sup>	1.6	6.9 <sup>a</sup>	9.7 <sup>a</sup>	8.3 <sup>a</sup>
Control	2.1 <sup>b</sup>	2.3 <sup>b</sup>	2.2	70.8 <sup>b</sup>	76.8 <sup>b</sup>	73.6 <sup>b</sup>
F- test	*	**	NS	**	**	**
LSD (0.05)	0.20	0.27	0.67	6.87	6.08	4.58
Maturity stage (B)						
MS2	1.7	1.7	1.7	13.5 <sup>a</sup>	16.7 <sup>a</sup>	15.1 <sup>a</sup>
MS3	1.8	1.5	1.6	21.9 <sup>b</sup>	22.9 <sup>b</sup>	22.4 <sup>b</sup>
MS4	1.9	1.6	1.7	31.2 <sup>c</sup>	30.2 <sup>c</sup>	30.7 <sup>c</sup>
F test	NS	NS	NS	**	**	**
LSD (0.05)	0.17	0.24	0.58	5.95	5.27	3.97
A×B	NS	NS	NS	NS	NS	NS
CV (%)	11.4	17.2	51	31.6	26.9	30.2

NS = Non-significant; \* and \*\* Significant at 0.05 and 0.01 levels, respectively. Figures in the column with same letter (s) do not differ significantly by DMRT at 0.05 level.

### Physiological weight loss (PWL, %)

The PWL increased in all the treatments with increased in storage period. Weight loss percentage was found maximum in control treatment until four DAS. The weight loss value varies from 3.9% to 10.5% during storage under ambient conditions. From the mean analysis of two years data (Table 2), the minimum mean difference percentage of PLW was observed in the fruits wrapped with fiber bag (2.8%) and fruits harvested at MS3 (3.2%) for storage whereas maximum weight loss was recorded in the unwrapped fruits (4.2% to 7.8%) and the fruits which were harvested at MS4 (4.4% to 7.6%). Fruit wrapped with white paper, fiber bag, and brown paper had relatively lower weight loss compared to unwrapped fruit under respective storage conditions.

**Table 2: Effect of wrapping materials and maturity stages on weight loss of papaya fruits during 8 days of storage under ambient conditions**

Treatment	% Weight loss at 4th DAS			% Weight loss at 8th DAS		
	2019	2020	Mean	2019	2020	Mean
Wrapping materials (A)						
Brown paper	3.9	4.0	3.9	6.6	7.3 <sup>a</sup>	6.9 <sup>a</sup>
White paper	3.5	3.8	3.7	6.6	7.0 <sup>a</sup>	6.8 <sup>a</sup>
Fiber bag	3.6	4.0	3.8	6.9	7.1 <sup>a</sup>	7.0 <sup>a</sup>
Control	4.4	4.4	4.4	7.7	8.4 <sup>b</sup>	8.1 <sup>b</sup>
F- test	NS	NS	NS	NS	*	*
LSD (0.05)	0.83	0.57	0.46	0.92	0.74	0.67
Maturity stage (B)						
MS2	3.8	3.7	3.7	7.2	7.1 <sup>a</sup>	7.1 <sup>a</sup>
MS3	3.8	3.8	3.8	10.5	7.2 <sup>a</sup>	8.8 <sup>c</sup>
MS4	3.9	4.6	4.2	8.2	8.0	8.1 <sup>b</sup>
F test	NS	*	*	NS	*	NS
LSD (0.05)	0.72	0.50	0.40	0.79	0.64	0.58
A×B	NS	NS	NS	NS	NS	NS
CV (%)	21	14.4	17.4	13.3	10.2	13.9

NS = Non-significant; \* and \*\* Significant at 0.05 and 0.01 levels, respectively. Figures with same letter (s) in the column do not differ significantly by DMRT at 0.05 level.

### Decay

The interaction effect of wrapping materials and harvesting stage on postharvest decay on 8<sup>th</sup> DAS was significant (Table 3). Decay was maximum (71.9%) in unwrapped fruits while it was least

(10.8%) in fruits wrapped with brown paper. The fruit harvested at MS2 showed the least decay (21.2%) at 8<sup>th</sup> DAS.

**Table 3: Effect of wrapping materials and maturity stages on decay (%) of papaya fruit on 8<sup>th</sup> DAS under ambient condition**

Treatment	% Decay at 8th DAS		
	2019	2020	Mean
Wrapping materials (A)			
Brown paper	12.2 <sup>a</sup>	9.4 <sup>a</sup>	10.8 <sup>a</sup>
White paper	26.7 <sup>b</sup>	17.2 <sup>b</sup>	21.9 <sup>b</sup>
Fiber bag	33.3 <sup>b</sup>	31.7 <sup>c</sup>	32.5 <sup>c</sup>
Control	73.3 <sup>c</sup>	70.6 <sup>d</sup>	71.9 <sup>d</sup>
F- test	**	**	**
LSD (0.05)	8.27	6.73	5.33
Maturity stage (B)			
MS 2	21.7 <sup>a</sup>	20.8 <sup>a</sup>	21.2 <sup>a</sup>
MS 3	33.3 <sup>b</sup>	29.2 <sup>b</sup>	31.2 <sup>b</sup>
MS 4	54.2 <sup>c</sup>	46.7 <sup>c</sup>	50.4 <sup>c</sup>
F test	**	**	**
LSD (0.05)	7.16	5.83	4.62
A×B	NS	*	*
CV%	23.4	21.5	23.3

NS = Non-significant; \* and \*\* Significant at 0.05 and 0.01 levels, respectively. Figures in the column with same letter (s) do not differ significantly by DMRT at 0.05 level.

### Shelf life

The main effect of different wrapping materials and maturity stage, and their interaction on the shelf life of papaya cv. Red Lady is shown in Table 4. Wrapping materials and maturity stages showed highly significant effect on the shelf life of papaya fruits in 2019 and 2020, and over the years. However, the interaction of wrapping materials and maturity stages had non-significant effect on shelf life in 2019 and 2020 but the pooled mean showed the significant effect. The fruits wrapped with brown paper showed the highest shelf life (12 days). The control treatment had the least shelf life (6 days) while shelf life of fruits wrapped with white paper and fiber bag did not showed differences. Similarly, the fruit harvested at MS2 had a longer shelf life (12 days) while fruits harvested at MS4 were stored only 6 days.

**Table 4: Effect of wrapping materials and maturity stages on the shelf life of papaya fruit stored under ambient condition**

Treatment	Shelf life (days)		
	2019	2020	Mean
Wrapping materials (A)			
Brown paper	11.8 <sup>a</sup>	11.8 <sup>a</sup>	11.8 <sup>b</sup>
White paper	10.2 <sup>a</sup>	11.5 <sup>a</sup>	10.8 <sup>a</sup>
Fiber bag	10.6 <sup>a</sup>	11.1 <sup>a</sup>	10.8 <sup>a</sup>
Control	6.6 <sup>b</sup>	6.3 <sup>b</sup>	6.5 <sup>c</sup>
F- test	**	**	**
LSD (0.05)	1.22	1.36	0.89
Maturity stage (B)			
MS2	12.0 <sup>c</sup>	12.8 <sup>b</sup>	12.4 <sup>c</sup>
MS3	10.8 <sup>b</sup>	11.7 <sup>b</sup>	11.2 <sup>b</sup>
MS4	6.7 <sup>a</sup>	6.5 <sup>a</sup>	6.6 <sup>a</sup>
F test	**	**	**
LSD (0.05)	1.06	1.18	0.77
A×B	NS	NS	*
CV%	12.7	13.7	13.2

NS = Non-significant; \* and \*\* Significant at 0.05 and 0.01 levels, respectively. Figures in the column with same letter (s) do not differ significantly by DMRT at 0.05 level.

### TSS (°Brix)

The TSS content of papaya fruits during the 8<sup>th</sup> DAS under different treatments are presented in Table 5. The TSS was increased with the increasing period of storage in all the treatments, and was higher in unwrapped fruits and the fruits harvested at MS4 stage. At the 8<sup>th</sup> DAS, the effect of wrapping materials showed non-significant TSS while the maturity stages resulted significant effect on TSS of papaya fruits.

**Table 5: Effect of wrapping materials and maturity stages on TSS (°Brix) of papaya fruit during 8 DAS under ambient condition**

Treatment	Initial TSS			TSS at 4th DAS			TSS at 8th DAS		
	2019	2020	Mean	2019	2020	Mean	2019	2020	Mean
Wrapping materials (A)									
Brown paper	7.3	6.7	7.0	7.9 <sup>a</sup>	8.0	8.0 <sup>a</sup>	9.0	9.1	9.1
White paper	7.5	6.9	7.2	8.4 <sup>b</sup>	8.1	8.2 <sup>b</sup>	9.2	9.2	9.2
Fiber bag	7.4	7.3	7.3	8.2 <sup>b</sup>	8.2	8.2 <sup>b</sup>	9.3	9.2	9.2
Control	7.4	7.1	7.3	8.4 <sup>b</sup>	8.3	8.3 <sup>b</sup>	9.3	9.1	9.2
F- test	NS	NS	NS	*	NS	*	NS	NS	NS
LSD (0.05)	0.27	0.52	0.31	0.24	0.35	0.20	0.23	0.25	0.15
Maturity stage (B)									
MS2	6.7 <sup>a</sup>	6.3 <sup>a</sup>	6.5 <sup>a</sup>	7.4 <sup>a</sup>	7.4 <sup>a</sup>	7.4 <sup>a</sup>	8.3 <sup>a</sup>	8.3 <sup>a</sup>	8.3 <sup>a</sup>
MS3	7.6 <sup>b</sup>	7.0 <sup>b</sup>	7.3 <sup>b</sup>	8.3 <sup>b</sup>	8.1 <sup>b</sup>	8.2 <sup>b</sup>	9.3 <sup>b</sup>	9.1 <sup>b</sup>	9.2 <sup>b</sup>
MS4	8.0 <sup>c</sup>	7.7 <sup>c</sup>	7.8 <sup>c</sup>	9.0 <sup>c</sup>	8.9 <sup>c</sup>	9.0 <sup>c</sup>	10.0 <sup>c</sup>	10.0 <sup>c</sup>	10.0 <sup>c</sup>
F test	**	**	**	**	**	**	**	**	**
LSD (0.05)	0.23	0.45	0.27	0.21	0.30	0.18	0.20	0.21	0.13
A×B	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	3.7	7.7	6.5	3.0	4.3	3.7	2.6	2.8	2.5

NS = Non-significant; \* and \*\* Significant at 0.05 and 0.01 levels, respectively. Figures in the column with same letter (s) do not differ significantly by DMRT at 0.05 level.

The combined mean of two years of TSS on 8<sup>th</sup> DAS showed that fruit harvested at MS4 had significantly the highest TSS (10°Brix) followed by MS3 (9.2°Brix) and the lowest (8.3°Brix) in MS2. However, the interaction effect of wrapping materials and stages of maturity showed non-significant effect.

### Firmness (kg/cm<sup>2</sup>)

Wrapping materials had significant effect on initial firmness and firmness on 4<sup>th</sup> day while non significant effect on firmness on 8<sup>th</sup> DAS.

**Table 6: Effect of wrapping materials and maturity stages on firmness (kg/cm<sup>2</sup>) of papaya fruit during 8 DAS under ambient condition**

Treatment	Initial firmness			Firmness 4th DAS			Firmness 8th DAS		
	2019	2020	Mean	2019	2020	Mean	2019	2020	Mean
Wrapping materials (A)									
Brown paper	4.2 <sup>c</sup>	4.2 <sup>b</sup>	4.2 <sup>b</sup>	3.6 <sup>b</sup>	3.6	3.6 <sup>b</sup>	2.9	2.8	2.8
White paper	4.0 <sup>b</sup>	4.0 <sup>a</sup>	4.0 <sup>a</sup>	3.3 <sup>a</sup>	3.3	3.3 <sup>a</sup>	2.7	2.7	2.7
Fiber bag	3.8 <sup>a</sup>	3.9 <sup>a</sup>	3.9 <sup>a</sup>	3.2 <sup>a</sup>	3.4	3.3 <sup>a</sup>	2.7	2.7	2.7
Control	3.9 <sup>a</sup>	3.9 <sup>a</sup>	3.9 <sup>a</sup>	3.4 <sup>a</sup>	3.3	3.3 <sup>a</sup>	2.8	2.7	2.7
F- test	**	*	**	*	NS	**	NS	NS	NS
LSD (0.05)	0.16	0.20	0.12	0.24	0.22	0.15	0.23	0.23	0.15
Maturity stage (B)									
MS2	5.9 <sup>c</sup>	6.0 <sup>c</sup>	6.0 <sup>c</sup>	5.3 <sup>c</sup>	5.3 <sup>c</sup>	5.3 <sup>c</sup>	4.5 <sup>c</sup>	4.4 <sup>c</sup>	4.5 <sup>c</sup>
MS3	3.2 <sup>b</sup>	3.3 <sup>b</sup>	3.2 <sup>b</sup>	2.6 <sup>b</sup>	2.7 <sup>b</sup>	2.7 <sup>b</sup>	2.1 <sup>b</sup>	2.0 <sup>b</sup>	2.0 <sup>b</sup>
MS4	2.8 <sup>a</sup>	2.8 <sup>a</sup>	2.8 <sup>a</sup>	2.2 <sup>a</sup>	2.2 <sup>a</sup>	2.2 <sup>a</sup>	1.7 <sup>a</sup>	1.7 <sup>a</sup>	1.7 <sup>a</sup>
F test	**	**	**	**	**	**	**	**	**
LSD (0.05)	0.15	0.17	0.10	0.21	0.29	0.13	0.20	0.20	0.13
A×B	NS	NS	*	NS	NS	NS	NS	NS	NS
CV (%)	4.5	5	4.3	7.2	6.7	6.7	8.4	8.6	8.6

NS = Non-significant; \* and \*\* Significant at 0.05 and 0.01 levels, respectively. Figures in the column with same letter (s) do not differ significantly by DMRT at 0.05 level.

Similarly, stage of maturity had a significant effect on the firmness of papaya fruits during initial conditions as well as during storage up to 8 days (Table 6). The firmness of a fruit decreased with advancement of maturity stage and with increasing storage period. At 8<sup>th</sup> DAS, fruits harvested at MS2 were firmer (4.5 kg/cm<sup>2</sup>) than harvested at MS4 (1.7 kg/cm<sup>2</sup>). However, their interaction effect was found non-significant on fruit firmness.

## **DISCUSSION**

This study found the lowest transportation loss (%) and bruised (%) wrapped with different wrapping materials and harvested at MS2. During the transportation of papaya from farm to market, fruits collide with each other or with the walls of the container resulting in the development of bruises or scratches. Wrapping materials prevents the fruits from scratching and abrasion that results low transportation loss and bruise. The physical evidence of such bruising is a result of cell breakage (Schoorl and Holt 1983), which results from stress and distortion of individual cells (Ruiz-Altisent and Moreda 2011). In this study, fruits without wrapping materials showed the highest bruise and damage. Respiration and moisture loss in unwrapped fruits might be associated with higher loss. Kumar et al (2016) also reported that respiration and moisture loss through injured skin alters the appearance of fruits and finally reduces the marketability. According to Burdon (1997), wrapping of fruits provides physical protection to fruits during transportation, handling, and marketing. Similarly, mechanical damage resulted during transportation can greatly accelerate the rate of water loss from produce. In our study the fruits wrapped with different materials showed less percentage of bruising damages as compared to unwrapped fruits. Azene et al (2014) reported the similar findings. The highest weight loss in control treatment at 8<sup>th</sup> DAS might be attributed to high respiration, and transpiration of water through the injured area, and other biological changes taking place in the fruit. In addition, changes in metabolic processes such as ethylene production and relative electrical conductivity usually lead to moisture loss, senescence, and spoilage (Ali et al 2011). The weight loss of wrapped fruits was lower which could be due to the minimum injuries that slows the rate of ripening and prevents excessive moisture loss. Similar results were also reported by Yamashita et al (2002) and Azene et al (2014).

The highest shelf life was found higher in wrapped fruits than unwrapped fruits. The wrapping materials either brown, white paper or fiber bag prevents the fruit from bruising that cause low respiration and ethylene production. Besides respiration and ethylene production, biological structure, transpiration, compositional changes, developmental processes, and physiological breakdown can all affect the shelf life of papaya (Irtwange 2006). The lower ethylene production reduced ethylene action, delayed ripening, and senescence increases the shelf life of papaya fruits. Similarly, decrease in the rate of respiration also increases the shelf life of fruits (Wills and Widjanarko 1995). Bruising damages during transportation of fruits results the microbial contamination that provides potential causes for fruit quality losses and lower shelf life in unwrapped fruits (Prusky 2011). Delayed respiration rates and ethylene could be a possible reason to extend the storage life of wrapped papaya fruits (Kader and Rolle 2004).

Fruits harvested at MS4 revealed the highest TSS. In general, the TSS value of papaya ranges from 7.4-19.0°Brix (Othman 2009). With the advancement of maturity stage, TSS increases. This could be due to accelerated ripening process and breakdown of carbohydrate polymer, especially starch to sugar (Azene et al 2014).

The highest firmness in MS2 was found which could be due to rigid middle lamella of the cell. Low firmness in fruits harvested at MS4 could be due to cell wall softening and could be the action of the softening promoting enzymes and high respiration rate. Kader and Rolle (2004) were also reported the similar results in horticultural produces. Many authors (Ali et al 2011; 2015) also reported that the action of the softening promoting enzymes, polygalacturonase, galactosidases, pectin methyl esterase and  $\beta$ -1,4-glucanases soften cell wall. The present result is in coherence with the findings of Zhou et al (2011) who found a decrease in fruit firmness with advancement in harvesting stages.

## CONCLUSION

In this experiment, wrapping materials showed a significant effect on transportation weight loss, bruised fruit (%), decay (%) during the storage period. Likewise, stages of maturity showed significant effect on bruised fruit (%), decay (%), shelf life, TSS, and fruit firmness whereas it showed non-significant effect on physiological weight loss. Wrapped fruits showed significantly less bruised fruit (%) after transportation which increases the marketability as well as shelf life of wrapped fruits during storage. Similarly, MS2 showed lowest bruised fruits, the highest shelf life as it remains fresh and firm for a longer duration. Harvesting of fruits based on market distance helps to prolong the shelf life of papaya using wrapping materials reduces the bruising damages during transportation. Therefore, wrapping the fruits with brown paper and harvesting at MS2 are effective in minimizing postharvest loss at various levels of marketing chains.

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