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Effects of non-chemical treatments on postharvest diseases, shelf life and quality of papaya under two different maturity stages

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Abstract

Papaya is a climacteric fruit and highly perishable in nature, which trigger ethylene production and hence, its consumption period is very short after harvesting. The experiment was conducted at the Laboratories of the Departments of Horticulture and Agricultural Chemistry, Bangladesh Agricultural University; and Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh during the period from March to June 2018 to study the effect of non-chemical treatments on postharvest diseases, shelf life and quality of papaya under two different maturity stages. The two-factor experiment consisted of two maturity stages viz. (i) Maturity stage 1 (M_1: mature green colour) and (ii) Maturity stage 2 (M_2: 0-10% yellowing); and six non-chemical treatments viz. (i) Control (T_0), (ii) Hot water treatment @ 50°C for 10 minutes (T_1), (iii) Gamma irradiation @ 0.08 kGy for 10 minutes (T_2), (iv) Chitosan coating @ 2% (T_3), (iv) Hot water + gamma irradiation (T_4), and (vi) Hot water + chitosan coating (T_5). The experiment was conducted in a completely randomized design (CRD) with 3 replications. The combined effect of maturity stages and non-chemical treatments were significant on all the parameters studied viz. external colour, weight loss, pulp to peel ratio, pulp pH, total soluble solids (TSS), disease incidence and severity, and shelf life of papaya. The papaya fruits under combined treatment of hot water plus gamma irradiation showed better appearance and external colour than the others at both maturity stages. The maximum weight loss was recorded in M_1T_0 (17.96%) followed by M_2T_0 (16.58%) while the minimum was found in M_1T_5 (3.69) followed by M_2T_5 (3.91). The highest pulp to peel ratio was observed in M_1T_4 (3.82) followed by M_1T_5 (3.78), while the lowest (3.00) was recorded in control under both maturity stages. The highest pulp pH was observed in M_2T_4 (6.15) followed by M_2T_5 (6.07) while the lowest was found in M_2T_0 (4.83) followed by M_1T_0 (5.05). The maximum disease incidence and severity were recorded (100%) in M_1T_0 and M_2T_0, whereas the minimum disease incidence (81%) and severity (12.36%) was found in M_1T_4. The longest shelf life (16.50 days) was obtained in M_1T_4 followed by M_2T_4 (15.25 days) and the shortest shelf life (8.65 days) was observed in M_2T_0 followed by M_1T_0 (9.25 days). Thus, hot water plus gamma irradiation followed by hot water plus chitosan coating under both maturity stages could be used to significantly reduce postharvest fungal infection, extend shelf life and improve quality of papaya.

Introduction

Papaya (*Carica papaya* Linn.) belongs to the family Caricaceae, is a very popular and an economically significant fruit crop in many tropical and subtropical countries. It has been emerged from the status of home garden crop to that of a commercial orchard in Bangladesh. Over the last decade there has been 55% expansion in production and the global export market of a little over 2.67 lakh tons has grown in value by 76% (FAO, 2014) but, clearly, most papaya enters local and national supply chains. Appearance, flavour and nutritional value of papaya fruits can be reduced by factors such as harvesting at an inappropriate stage of maturity (Greenwel *et al.,* 1997), extreme or fluctuating storage and transport temperatures (Paull *et al.,* 1994; Pimentel and Walder, 2004) and mechanical damage resulting from poor handling practices (Chen *et al.,* 2007; Proulx *et al.,* 2005).

Recently 4.93 lakh tons of papaya was produced in Bangladesh from an area of 19.4 thousand hectares of land which is quite satisfactory (BBS, 2018), although approximately 40% produce is damaged due to postharvest loss which is a major problem for papaya producers, traders and consumers in the country (FAO, 2019). After harvesting, the fruits start to live by using their own reserves and fruits mature progressively and during the storage, conditions are favourable to microorganisms, which cause fruit damage. Postharvest losses, reduction of shelf life and marketing quality of papaya owes much to fungal rot, particularly infection by anthracnose (*Colletotrichum gleosporioides*) and other pathogens that vary with location (Bautista-Banos *et al.,* 2013; Lacroix *et al.*, 1990; Palhano *et al.,* 2004). In addition, its sensitiveness to low temperature increases difficulties of papaya during storage.

Harvesting at proper maturity stage is a very important determinant for storage-life and final fruit quality. If fruits are harvested at improper maturity, it can lead to

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uneven ripening and over ripe fruits. The postharvest losses of papaya can be reduced by prolongation of shelf life which can improve the present situation. Heat treatments at different temperatures with appropriate time can be successfully applied for the disinfestations of disease and insect pests in fresh fruit (Armstrong, 1994). Rashid *et al*. (2015) reported that low doses (<1 kGy) of gamma irradiation treatment of mature green papayas appear to be a promising process of shelf-life extension by delaying the ripening and senescence, the fungal decay and for the disinfestations. In addition, chitosan at 2% and 3% showed a fungicidal effect against *Colletotrichum gloeosporioides* (Bautista-Baños *et al*., 2003). Chitosan is a polysaccharide composed of randomly distributed β-(1→4)-linked D-glucosamine (deacetylated unit) and N-acetyle-D-glucosamine (acetylated unit) which was made by treating the chitin shells of shrimp with an alkaline substance, like sodium hydroxide. However, still very little information is available about single and combined application of hot water dipping and non-chemical treatments (Pimentel and Walder, 2004). Papaya postharvest research related to fruit ripening and handling became more important during the last decade because of increasing consumer awareness of papaya and of the expansion in production and exports. The present study was therefore been undertaken to study the effect of non-chemical treatments on postharvest diseases, shelf life and quality of papaya under two different maturity stages.

Materials and Methods

The experiment was conducted to study the effect of non-chemical treatments on postharvest diseases, shelf life and quality of papaya under two different maturity stages at the Laboratories of the Departments of Horticulture and Agricultural Chemistry, Bangladesh Agricultural University, Mymensingh, and Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh during the period from March to June 2018.

Experimental materials

Papaya fruits (*var.* Shahi) of two maturity stages were collected from growers on the basis of uniform in shape, size, weight and without visible imperfections or quality defects. Fruits were sorted into two distinct groups at maturity stage 1 (M_1) with mature green colour and maturity stage 2 (M_2) with 0-10% yellowing on the fruit surface cover (Pimentel and Walder, 2004). On arrival at the laboratory, the fruits were washed with water, cleaned properly, allowed to dry in air. The size of the fruits was on average 600–700 g in weight. After grading, the fruits were then individually wrapped in non-absorbent paper and kept under ambient temperature (25 ± 1°C) prior to further treatments.

Treatments of the investigation and experimental design

The experiment consisted of two factors viz. factor A: two maturity stages: (i) Maturity stage 1 (M_1: mature green colour) and (ii) Maturity stage 2 (M_2: 0-10% yellowing on the fruit surface); and factor B: six non-chemical treatments: (i) Control or untreated fruits (T_0), (ii) Fruits treated with hot water dipping at 50°C for 10 minutes (T_1), (iii) Fruits irradiated with a dose of 0.08 kGy for 10 minutes (T_2), (iv) Chitosan coating @ 2% (T_3), (iv) Combined treatment of hot water plus gamma irradiation (T_4), and (vi) Combined treatment of hot water plus chitosan coating (T_5). The experiment was conducted in a completely randomized design (CRD) with 3 replications.

Application of the postharvest treatments

Papaya fruits with six treatments under maturity index 1 and 2 were taken in this study. The postharvest treatments were sequentially applied to the selected fruits. Then the treated fruits were kept under ambient temperature (25 ± 1°C) for normal ripening. All changes of the fruits during storage were monitored every 3 days interval. For control treatment ten fruits under each treatment of two maturity stages were selected randomly from a papaya fruit lot, washed and air-dried. For hot water treatment tap water was kept in an electric hot water bath and 50°C was maintained. Fruits were individually dipped into the hot water for the period of 10 minutes and air-dried. For individual treatment of gamma irradiation the selected fruits under both maturity stages were taken to the irradiation laboratory of BINA after the day of harvesting. Then the irradiation was conducted at the rate of 0.08 kGy h-1 for 10 minutes, through a Cobalt-60 source type Gamma beam 650. For chitosan coating the selected fruits under both maturity stages were dipped at 2% chitosan solution for 2 minutes and air-dried. Chitosan was prepared from shrimp shell. Chitosan solution (2%) was prepared by dissolving 2 g of chitosan in 90 mL of distilled water added with 2 mL of glacial acetic acid. The mixture was heated with continuous stirring for proper dissolution of chitosan. The final pH of the solution was adjusted to 5.6 with 2 N NaOH and made up to 100 mL with distilled water. To improve the wettability of 0.1 mL Tween 20 was added to the solution.

Parameters studied

The parameters of papaya taken in this experiment were colour changes of the fruits, weight loss, total soluble solids (TSS) content of pulp, pulp pH, disease incidence (percentage of infected fruits) and severity (percentage of skin infected fruits), and shelf life of papaya. The parameters were measured in the following ways:

External colour: Papaya fruits of two maturity stages were observed carefully and visually examined from the day of treatment to the whole storage period under different postharvest treatments and were regularly evaluated and noted.

Weight loss of the fruits: Weight loss of papaya was measured by weighing the individual fruits every 3 days interval by using a top pan electric balance. Five fruits per treatment were taken to mark for this purpose and same fruits were used until the end of the experiment. The percentage of weight loss was calculated by using the following formula:

$$\% \text{ Weight loss} = \frac{W_1 - W_2}{W_1} \times 100$$

Where, W_1 = Initial weight of the fruit (0 days)

W_2 = Fruits weight at various storage periods (0, 3, 6, 9, 12 days)

Pulp to peel ratio: The papaya fruits were placed at 3 days interval starting 3 days after scoring. Pulp to peel ratio was determined by separately weighing pulps and peels of fruits of each treatment and each replication by using electrical balance. The pulp to peel ratio was measured by the ratio of weight of fruit pulp to weight of peel.

Pulp pH: The pH of fruit juice was recorded by using an electric pH meter, which was standardized with the help of a buffer solution as described by Ranganna (1994).

Total soluble solids (TSS) content of pulp: Total soluble solids concentration of papaya pulp was determined by using a hand refractometer (Model N-1 α, Atago, Japan). The remaining juice from pH determination was used to measure the TSS of the fruit pulp. Before measurement, the refractometer was calibrated with distilled water to give a zero reading. One or two drops of the filtrate was placed on the prism glass of the refractometer to obtain the %TSS reading. The reading was multiplied by dilution factor to obtain an original %TSS of the pulp tissues. Since differences in sample temperature could affect the TSS measurement, temperature corrections were made by using the methods described by Ranganna (1979).

Disease incidence (percentage of infected fruits): Five fruits for each treatment were critically examined every day for the appearance of the disease symptoms and the incidence was recorded every 3 days. The first count was made at the 3rd day of storage. The disease development was identified by the visual comparison with those of the symptoms already published (Al Eryani-Raqeeb *et al*., 2009). A total of three fungal diseases like anthracnose, stem end rot and Rhizopus rot were identified by observing the typical symptoms of those diseases which were caused by *Colletotrichum gloeosporioides*, *Botryodiplodia theobromae* and *Rhizopus stolonifer*, respectively. Disease incidence of the fruit was calculated by the following formula:

$$\% \text{ Disease incidence} = \frac{\text{Number of infected fruits}}{\text{Total number of fruits assessed}} \times 100$$

Disease severity (percentage of skin infected fruits by fungal diseases): In order to measure disease severity level, the fruits were critically observed and the percent skin infected fruits was recorded every day starting from the 3rd day of storage upto the 12th day. All the infected fruits were taken to determine the percent fruit area infected and carefully evaluated. This evaluation was determined by eye estimation by calculating the mean values regarding the infected fruit areas. The assessment of this characteristic was done subjectively through scores related to the following scale adapted from Azevedo (1998): 1. Very bad – more than 50% of fruit with lesions, impossible to be made good use of; 2. Bad – lesions between 25 and 50% of fruit, not much exploitable; 3. Tolerable – lesions between 5 and 25% of fruit, not acceptable for trading, can be used as home consumption; 4. Good – lesions up to 5% of fruit, conditions acceptable for trading; 5. Excellent – without lesions, perfect phytosanitary quality.

Shelf life: In order to determine the shelf life, five fruits were taken for the each treatment for both the two maturity stages every 3 days interval. Then the treated fruits were kept under ambient temperature (25 ± 1°C) for normal ripening. Shelf life of fruits was calculated by counting the days required for fully ripe as to retaining optimum marketing and eating qualities.

Statistical analysis

The collected data were statistically analyzed by using ANOVA (Analysis of variance method) where the significance of difference between pair of means was tested by least significant difference (LSD) at 5% (α = 0.05) level of probability using MSTAT Computer programme.

Results and Discussion

External colour

The change in peel colour was noticeable in both maturity stages as influenced by different non-chemical treatments (Table 1 & Figs. 1–4). The results revealed that the changes in colour of non-treated and hot water treated fruits were observed earlier than the gamma irradiated and chitosan treated fruits under both maturity stages. Until 6 days after storage (DAS), no significant difference in colour changes was observed in the postharvest treatments under both maturity stages. At 9 DAS, peel colour was greenish yellow in combined treatment of hot water plus gamma irradiated (M_1T_4) and hot water plus chitosan coated (M_1T_5) fruits while light greenish yellow in rest of the treatments of M1 stage. On the other hand, peel colour was light greenish yellow in combined treatment of hot water plus gamma irradiated (M_2T_4) and hot water plus chitosan coated (M_2T_5) fruits while yellow in rest of the treatments of M2 stage. It might be due to the smaller number of persistent green spots found in irradiated papaya, which would not turn yellow, hence irradiated papaya ripened in a more homogenous way. At 12 DAS, peel colour was light greenish yellow in combined treatment of hot water plus gamma irradiated (M_1T_4) and hot water plus chitosan coated (M_1T_5) fruits, while yellow in control and rest of the treatment combinations under both maturity stages. In the control, protoplast was changed into chromoplast normally, while in treated samples, this process was suppressed due to the treatment effect. The changes of these components affected the fruit colour from green into yellow in the skin. The results showed that combined treatment had better appearance than the others of both maturity stages.

Weight loss

Weight loss of papaya fruits were significantly influenced by the combined effect of maturity stages and non-chemical treatments (Table 2). Results showed that weight loss was gradually increased with storage period. At 12 DAS, the maximum weight loss was recorded in M_1T_0 (17.96%) followed by M_2T_0 (16.58%) while the minimum weight loss was found in M_1T_5 (3.69) followed by M_2T_5 (3.91). Miller & McDonald (1999) also found difference in weight loss between irradiated and non-irradiated papaya in two maturation stages (mature green and 25% ripe). However, irradiation can break chemical bonds, increasing membrane permeability and metabolic activity, which will lead to more water vapor movement to intercellular space, and then through cuticle, increasing transpiration.

Pulp to peel ratio

Combined effects of maturity stages and non-chemical treatments had significant influence on pulp to peel ratio of papaya fruits except 3 DAS (Table 2). Pulp to peel ratio showed a decreasing trend from harvest to ripening. At 12 DAS, the highest pulp to peel ratio was observed in M_1T_4 (3.82) followed by M_1T_5 (3.78), while the lowest pulp to peel ratio (3.00) was observed in control under both maturity stages (M_1T_0 and M_2T_0, respectively). The decreased ratio during storage may be related to the change in sugar concentration in the peel compared to the pulp thus contributing to different change in osmotic pressure.

Pulp pH

Combined effects of maturity stages and non-chemical treatments exhibited significant variation in respect of pulp pH during storage except 6 DAS (Table 3). Results showed that pulp pH was increased with duration of storage. At 12 DAS, the highest pulp pH was observed in M_2T_4 (6.15) followed by M_2T_5 (6.07). In contrast, the lowest pulp pH was recorded in M_2T_0 (4.83) followed by M_1T_0 (5.05). This could be due to the increasing fashion of papaya pH during storage.

Total soluble solids (TSS) content

The combined effect of maturity stages and postharvest treatments in relation to TSS content was significant at all the stages of storage period (Table 3). It was observed that TSS content in pulp gradually increased during the storage period irrespective to all treatments, which similar to the investigation of Ghanta (1994). At 12 DAS, the highest TSS (16.60%) was observed in the treatment combinations of M_2T_4 followed by M_1T_4 (16.20%), whereas it was lowest in M_1T_0 (12.30%). This could be due to the hydrolysis of starch into sugar. A similar result was also reported by Pimentel and Walder (2004). Sugar content is one of the main components of quality of papaya, so it is important that papaya should be harvested more mature and, if possible, in the maturation stage that elicits higher sugar concentration. Irradiation in fruits with higher starch content, like banana and mango, suffer alterations in soluble solids. However, the amount of starch in papayas is very low; therefore, there was no room for alteration in sugar content. Rashid *et al.* (2015) found that the combined treatment had no significant, negative impact on ripening, with quality characteristics such as surface and internal colour change, firmness, soluble solids, acidity and vitamin C maintained at acceptable levels.

Disease incidence

Papaya postharvest diseases were observed from the 3rd DAS and it increased with the progress of storage period. During storage period, a total of three fungal diseases like anthracnose, stem end rot and Rhizopus rot were identified by observing the typical symptoms of those diseases which were caused by *Colletotrichum gloeosporioides*, *Botryodiplodia theobromae* and *Rhizopus stolonifer*, respectively (Fig. 5).

Assesment of percent disease incidence

The combined effect of maturity stages and non-chemical treatments had significant influence on disease incidence of papaya (Table 4). The disease incidence increased with the storage period and the highest disease incidence (100%) was found in control treatment at the end of the storage period (12 days after storage) under both maturity stages (M_1T_0 and M_2T_0) and the lowest was observed in in M_1T_4 (81%) followed by M_2T_4 (82%) and M_1T_5 (83%), respectively. Similar result was also found by Rashid *et al.* (2015), who found that low-dose gamma irradiation (0.08 kGy over 10 min), a level significantly below that required to satisfy the majority of international quarantine regulations, has been employed to provide a significant reduction in visible fungal infection on papaya fruit surfaces. Combination treatments such as heating and irradiation may give synergistic effect and could give less detrimental effect to quality attributes of the papaya fruits. Miller and McDonald (1999) also reported that decay was manifested more in 1/3 yellow coloured fruits than mature green stage, probably because of the higher incidence of peel injuries during handling; decay organisms are known to enter into fruit at sites of injury. Gamma irradiation is a physical treatment that does not leave residues on the fruit and can help to reduce the postharvest use of fungicides. Cia *et al.* (2007) also reported that doses of 0.75 and 1 kGy could exhibit positive direct and indirect effects on *Colletotrichum gloeosporioides*.

Table 1. Combined effect of maturity stages and non-chemical treatments on external colour changes at different days after storage (DAS) of papaya

Treatment combination	Colour changes at different DAS			
	3	6	9	12
M_1T_0	Pale green	Greenish yellow	Light greenish yellow	Yellow
M_1T_1	Pale green	Greenish yellow	Light greenish yellow	Yellow
M_1T_2	Pale green	Greenish yellow	Light greenish yellow	Yellow
M_1T_3	Pale green	Greenish yellow	Light greenish yellow	Yellow
M_1T_4	Pale green	Pale green	Greenish yellow	Light greenish yellow
M_1T_5	Pale green	Pale green	Greenish yellow	Light greenish yellow
M_2T_0	Greenish yellow	Light greenish yellow	Yellow	Yellow
M_2T_1	Greenish yellow	Light greenish yellow	Yellow	Yellow
M_2T_2	Greenish yellow	Greenish yellow	Yellow	Yellow
M_2T_3	Greenish yellow	Greenish yellow	Yellow	Yellow
M_2T_4	Greenish yellow	Greenish yellow	Light greenish yellow	Yellow
M_2T_5	Greenish yellow	Greenish yellow	Light greenish yellow	Yellow

M_1 = Maturity stage 1 (Mature green colour), M_2 = Maturity stage 2 (0-10% yellowing on the fruit surface), T_0 = Control or untreated fruits, T_1 = Hot water treatment @ 50°C for 10 minutes, T_2 = Gamma irradiation @ 0.08 kGy for 10 minutes, T_3 = Chitosan coating @ 2%, T_4 = Hot water + gamma irradiation, T_5 = Hot water + chitosan coating.

Table 2. Combined effect of maturity stages and non-chemical treatments on weight loss and pulp to peel ratio at different days after storage (DAS) of papaya

Treatment combination	Weight loss (%) at different DAS				Pulp to peel ratio at different DAS			
	3	6	9	12	3	6	9	12
M_1T_0	2.51	4.55	10.87	17.96	4.75	4.55	3.25	3.00
M_1T_1	2.18	6.16	8.91	12.78	5.12	5.03	3.55	3.07
M_1T_2	2.87	5.88	8.72	11.52	5.75	5.62	4.43	3.35
M_1T_3	2.69	5.02	7.24	9.93	5.74	5.36	4.25	3.36
M_1T_4	0.78	1.78	2.86	4.43	5.95	5.88	4.78	3.82
M_1T_5	1.37	2.04	2.86	3.69	5.89	5.81	4.71	3.78
M_2T_0	3.09	7.91	12.26	16.58	4.71	4.51	3.15	3.00
M_2T_1	3.21	6.78	8.89	12.53	5.16	4.75	3.35	3.09
M_2T_2	2.80	4.90	6.71	9.90	5.75	5.35	4.26	3.40
M_2T_3	2.10	4.68	7.56	10.69	5.71	5.32	4.15	3.33
M_2T_4	0.49	1.45	2.76	4.20	5.86	5.32	4.35	3.50
M_2T_5	1.09	2.07	2.93	3.91	5.81	5.15	4.20	3.45
$LSD_{0.05}$	0.18	0.61	0.18	0.55	0.12	0.11	0.15	0.08
Level of significance	*	*	*	*	NS	*	*	*

*= Significant at 5% level of probability, NS= Not significant, M_1 = Maturity stage 1 (Mature green colour), M_2 = Maturity stage 2 (0-10% yellowing on the fruit surface), T_0 = Control or untreated fruits, T_1 = Hot water treatment @ 50°C for 10 minutes, T_2 = Gamma irradiation @ 0.08 kGy for 10 minutes, T_3 = Chitosan coating @ 2%, T_4 = Hot water + gamma irradiation, T_5 = Hot water + chitosan coating.

Table 3. Combined effect of maturity stages and non-chemical treatments on pulp pH and total soluble solids (TSS) content of papaya at different days after storage (DAS)

Treatment combination	Pulp pH at different DAS				TSS content (% brix) at different DAS			
	3	6	9	12	3	6	9	12
M_1T_0	3.17	3.30	3.59	5.05	11.40	11.70	12.00	12.30
M_1T_1	4.55	4.69	5.15	5.65	11.90	12.20	12.60	12.90
M_1T_2	4.68	4.82	5.26	5.94	12.00	12.60	13.20	13.80
M_1T_3	4.65	4.76	5.21	5.85	11.70	12.10	12.70	13.50
M_1T_4	4.70	4.91	5.12	5.92	12.20	13.40	14.90	16.20
M_1T_5	4.65	4.86	5.02	5.83	12.00	12.80	13.60	14.20
M_2T_0	3.12	3.25	3.51	4.83	11.60	11.90	12.20	12.60
M_2T_1	4.62	4.75	5.15	5.70	12.00	12.40	12.70	13.20
M_2T_2	4.70	4.84	5.28	5.99	12.20	12.90	13.60	14.20
M_2T_3	4.66	4.78	5.24	5.88	11.50	12.00	12.60	13.10
M_2T_4	4.80	4.88	5.35	6.15	12.50	13.90	15.20	16.60
M_2T_5	4.78	4.85	5.32	6.07	12.10	12.90	13.80	14.60
$LSD_{0.05}$	0.08	0.16	0.18	0.11	0.11	0.21	0.09	0.08
Level of significance	*	NS	*	*	*	*	*	*

*= Significant at 5% level of probability, NS= Not significant, M_1 = Maturity stage 1 (Mature green colour), M_2 = Maturity stage 2 (0-10% yellowing on the fruit surface), T_0 = Control or untreated fruits, T_1 = Hot water treatment @ 50°C for 10 minutes, T_2 = Gamma irradiation @ 0.08 kGy for 10 minutes, T_3 = Chitosan coating @ 2%, T_4 = Hot water + gamma irradiation, T_5 = Hot water + chitosan coating.

Table 4. Combined effect of maturity stages and non-chemical treatments on disease incidence and severity of papaya at different days after storage (DAS)

Treatment combination	Disease incidence (%) at different DAS				Disease severity (%) at different DAS			
	3	6	9	12	3	6	9	12
M_1T_0	18	26	62	100	3.35	7.12	28.27	75.23
M_1T_1	6	15	55	90	0.15	1.33	33.25	72.25
M_1T_2	0.00	11	43	76	0.00	1.25	25.50	65.25
M_1T_3	0.00	14	48	87	0.00	1.52	28.36	68.38
M_1T_4	0.00	9	43	81	0.00	0.25	5.25	12.36
M_1T_5	0.00	12	47	83	0.00	0.95	9.20	36.25
M_2T_0	21	42	96	100	15.35	43.25	95.25	100.00
M_2T_1	12	25	67	98	1.75	8.25	46.20	65.26
M_2T_2	6	13	56	90	0.05	5.25	40.20	52.38
M_2T_3	7	17	68	95	1.02	6.36	43.35	59.20
M_2T_4	0.00	10	44	82	0.00	0.50	7.32	13.26
M_2T_5	0.00	13	59	92	0.00	1.23	10.25	38.27
$LSD_{0.05}$	0.60	0.80	1.00	2.00	0.24	1.12	2.06	1.55
Level of significance	*	*	*	*	*	*	*	*

*= Significant at 5% level of probability, NS= Not significant, M_1 = Maturity stage 1 (Mature green colour), M_2 = Maturity stage 2 (0-10% yellowing on the fruit surface), T_0 = Control or untreated fruits, T_1 = Hot water treatment @ 50°C for 10 minutes, T_2 = Gamma irradiation @ 0.08 kGy for 10 minutes, T_3 = Chitosan coating @ 2%, T_4 = Hot water + gamma irradiation, T_5 = Hot water + chitosan coating.

Figures

T_0 T_1 T_2 T_3 T_4 T_5

Figure 1a. Photograph showing the differences in external appearance of papaya fruits of maturity stage 1 (M_1) under different postharvest treatments at 3 DAS. T_0 = Control or untreated fruits, T_1 = Hot water treatment @ 50°C for 10 minutes, T_2 = Gamma irradiation @ 0.08 kGy for 10 minutes, T_3 = Chitosan coating @ 2%, T_4 = Hot water + gamma irradiation, T_5 = Hot water + chitosan coating.

T_0 T_1 T_2 T_3 T_4 T_5

Fig. 1b. Photograph showing the differences in external appearance of papaya fruits of maturity stage 2 (M_2) under different postharvest treatments at 3 DAS. T_0 = Control or untreated fruits, T_1 = Hot water treatment @ 50°C for 10 minutes, T_2 = Gamma irradiation @ 0.08 kGy for 10 minutes, T_3 = Chitosan coating @ 2%, T_4 = Hot water + gamma irradiation, T_5 = Hot water + chitosan coating.

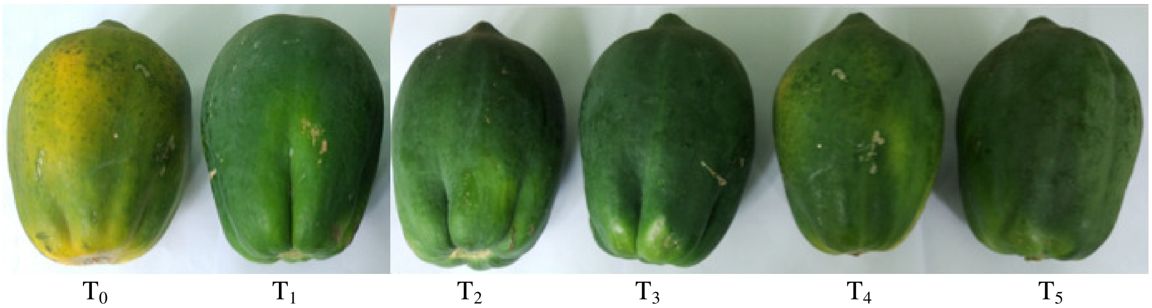

Fig. 2a. Photograph showing the differences in external appearance of papaya fruits of maturity stage 1 (M_1) under different postharvest treatments at 6 DAS. T_0 = Control or untreated fruits, T_1 = Hot water treatment @ 50°C for 10 minutes, T_2 = Gamma irradiation @ 0.08 kGy for 10 minutes, T_3 = Chitosan coating @ 2%, T_4 = Hot water + gamma irradiation, T_5 = Hot water + chitosan coating.

Fig. 2b. Photograph showing the differences in external appearance of papaya fruits of maturity stage 2 (M_2) under different postharvest treatments at 6 DAS. T_0 = Control or untreated fruits, T_1 = Hot water treatment @ 50°C for 10 minutes, T_2 = Gamma irradiation @ 0.08 kGy for 10 minutes, T_3 = Chitosan coating @ 2%, T_4 = Hot water + gamma irradiation, T_5 = Hot water + chitosan coating.

Fig. 3a. Photograph showing the differences in external appearance of papaya fruits of maturity stage 1 (M_1) under different postharvest treatments at 9 DAS. T_0 = Control or untreated fruits, T_1 = Hot water treatment @ 50°C for 10 minutes, T_2 = Gamma irradiation @ 0.08 kGy for 10 minutes, T_3 = Chitosan coating @ 2%, T_4 = Hot water + gamma irradiation, T_5 = Hot water + chitosan coating.

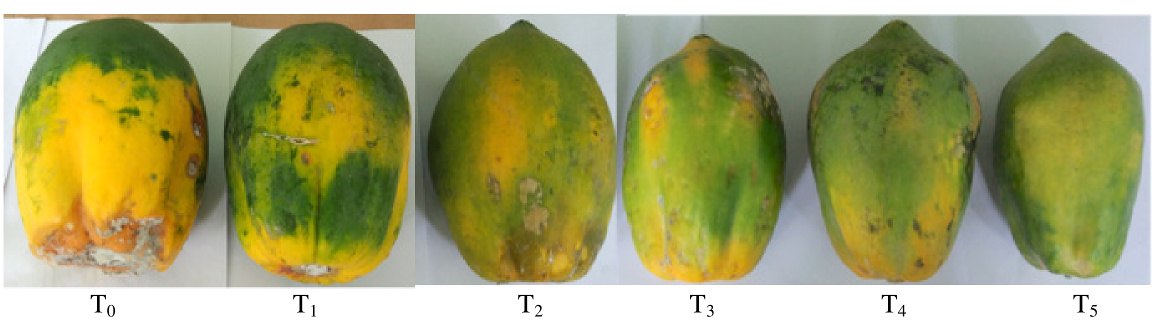

Fig. 3b. Photograph showing the differences in external appearance of papaya fruits of maturity stage 2 (M_2) under different postharvest treatments at 9 DAS. T_0 = Control or untreated fruits, T_1 = Hot water treatment @ 50°C for 10 minutes, T_2 = Gamma irradiation @ 0.08 kGy for 10 minutes, T_3 = Chitosan coating @ 2%, T_4 = Hot water + gamma irradiation, T_5 = Hot water + chitosan coating.

T_0 T_1 T_2 T_3 T_4 T_5

Fig. 4a. Photograph showing the differences in external appearance of papaya fruits of maturity stage 1 (M_1) under different postharvest treatments at 12 DAS. T_0 = Control or untreated fruits, T_1 = Hot water treatment @ 50°C for 10 minutes, T_2 = Gamma irradiation @ 0.08 kGy for 10 minutes, T_3 = Chitosan coating @ 2%, T_4 = Hot water + gamma irradiation, T_5 = Hot water + chitosan coating.

T_0 T_1 T_2 T_3 T_4 T_5

Fig. 4b. Photograph showing the differences in external appearance of papaya fruits of maturity stage 2 (M_2) under different postharvest treatments at 12 DAS. T_0 = Control or untreated fruits, T_1 = Hot water treatment @ 50°C for 10 minutes, T_2 = Gamma irradiation @ 0.08 kGy for 10 minutes, T_3 = Chitosan coating @ 2%, T_4 = Hot water + gamma irradiation, T_5 = Hot water + chitosan coating.

a b c

Fig. 5. Photograph showing (a) Anthracnose (*Colletotrichum gloesporioides*), (b) Stem end rot (*Botryodiplodia theobromae*) and (c) Rhizopus fruit rot (*Rhizopus stolonifer*) of papaya in control treatment.

Disease severity

The combined effect of maturity stages and postharvest treatments had significant effect on disease severity of papaya (Table 4). Like disease incidence, the disease development also increased with the storage period and the highest disease severity (100%) was found at the end of the storage period (12 DAS) under M_2T_0 and the lowest disease severity (12.36%) in M_1T_4 followed by (13.36%) in M_2T_4. This result could be supported by the similar findings of Rashid *et al*. (2015), where it was reported that the incidence and severity of surface fungal infections including anthracnose were significantly reduced by the combined treatment compared to irradiation or hot water treatment alone, extending storage at 11 °C by 13 days and retaining commercial acceptability.

Shelf life

Shelf life is the period from harvesting up to the last edible stage. This is the basic quality of fruits which helps long marketing time and it is the most important aspect in loss reduction technology of fruits. The extension of shelf life of fruit has been one of the prime concerns of marketing throughout the record of history. Statistically there was significant difference between the two maturity stages with respect to shelf life of papaya (Fig. 6). The results showed that the shelf life of M_1 stage fruits (13.49 days) was higher than that of M_2 stage fruits (12.98 days).

Without considering the maturity stage, the non-chemical treatments exhibited pronounced effect on extending the shelf life of papaya (Fig. 7). The longest shelf life (15.88 days) was recorded in fruits with combined treatment of hot water and gamma irradiation (T_4) followed by (14.88) with hot water plus chitosan coating (T_5), whereas the minimum shelf life (8.95 days) was recorded in control (T_0). The delay in ripening on irradiated and chitosan coated fruits can occur due to the lower capacity of these fruits in producing ethylene, since this hormone has a stimulation role in the general metabolism, and seems to be implicated in the activation and regulation of some enzymes involved in ripening (Gomez *et al*., 1999).

The combined effect of maturity stages and non-chemical treatments had significant influence on shelf life of papaya (Table 5 & Fig. 8). The longest shelf life (16.50 days) was obtained in M_1T_4 followed by M_2T_4 (15.25 days) and the minimum shelf life (8.65 days) was observed in M_2T_0 followed by M_1T_0 (9.25 days). Similar result was also reported by Pimentel and Walder (2004), as they investigated on the effects of the maturity stage of papaya fruit at the time of irradiation and reported a correlation between the efficiency of gamma radiation and maturity stage in delaying the ripening process. The above results showed that gamma irradiation alone and combined with hot water treatment might significantly influence the shelf life of papaya. The increase in shelf life was probably due to the changes in the concentrations of various gases like the increase of O_2, the reduction of CO_2 and ethylene as well as the slowing down of the processes leading to delayed ripening and reducing decay by gamma irradiation and hot water treatments.

Table 5. Combined effect of maturity stages and non-chemical treatments on shelf life of papaya

Maturity stage × Non-chemical treatments	Shelf life (days)
M_1T_0	9.25
M_1T_1	11.35
M_1T_2	14.20
M_1T_3	14.65
M_1T_4	16.50
M_1T_5	15.00
M_2T_0	8.65
M_2T_1	11.25
M_2T_2	13.95
M_2T_3	14.00
M_2T_4	15.25
M_2T_5	14.75
$LSD_{0.05}$	0.40
Level of significance	*

*= Significant at 5% level of probability, NS= Not significant, M_1 = Maturity stage 1 (Mature green colour), M_2 = Maturity stage 2 (0-10% yellowing on the fruit surface), T_0 = Control or untreated fruits, T_1 = Hot water treatment @ 50°C for 10 minutes, T_2 = Gamma irradiation @ 0.08 kGy for 10 minutes, T_3 = Chitosan coating @ 2%, T_4 = Hot water + gamma irradiation, T_5 = Hot water + chitosan coating.

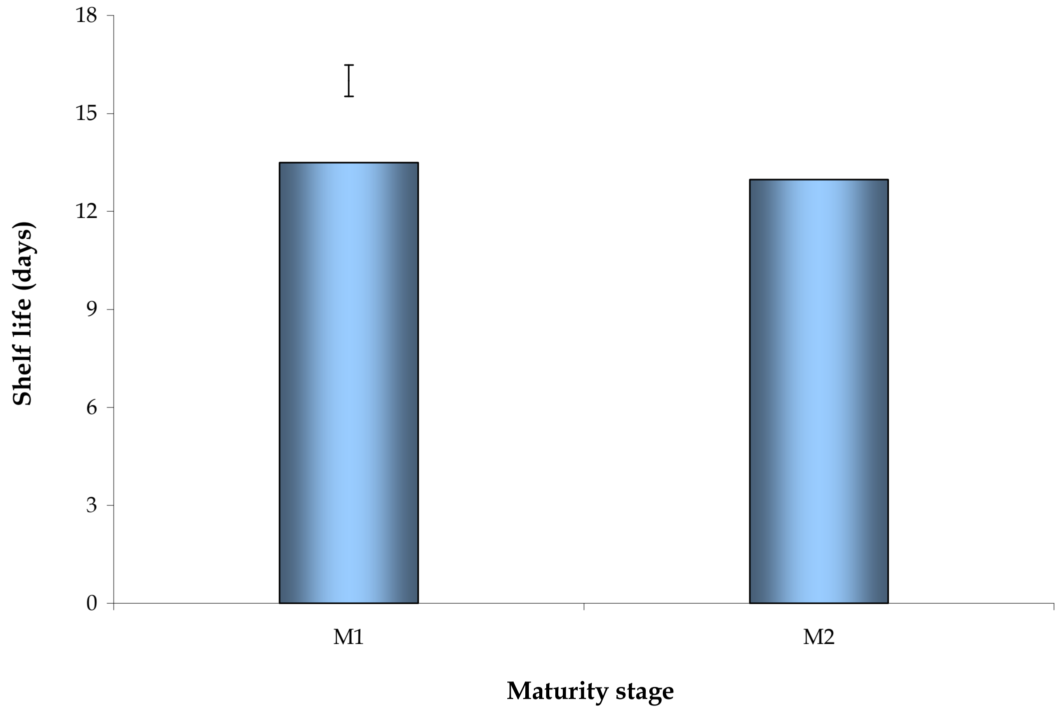

Fig. 6. Effect of maturity stages on shelf life of papaya during storage. The vertical bar represents LSD at 5% level of probability. M_1 = Maturity stage 1 (Mature green colour), M_2 = Maturity stage 2 (0-10% yellowing on the fruit surface).

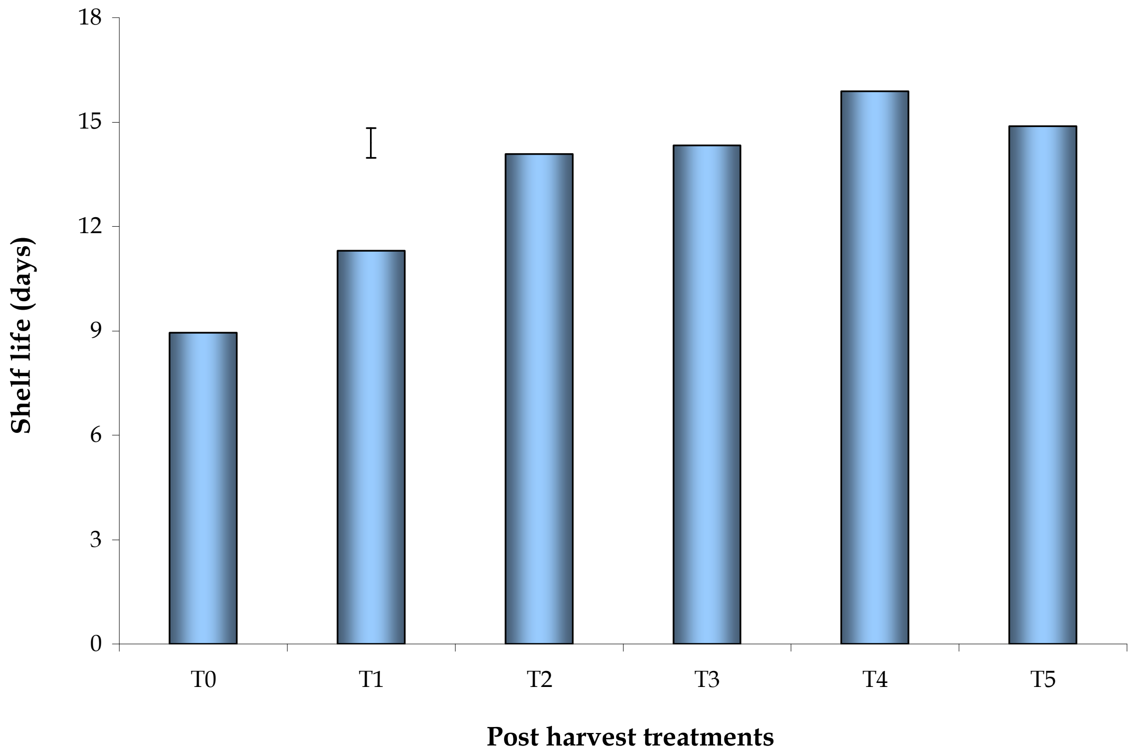

Fig. 7. Effect of non-chemical treatments on shelf life of papaya during storage. The vertical bar represents LSD at 5% level of probability. T_0 = Control or untreated fruits, T_1 = Hot water treatment @ 50°C for 10 minutes, T_2 = Gamma irradiation @ 0.08 kGy for 10 minutes, T_3 = Chitosan coating @ 2%, T_4 = Hot water + gamma irradiation, T_5 = Hot water + chitosan coating.

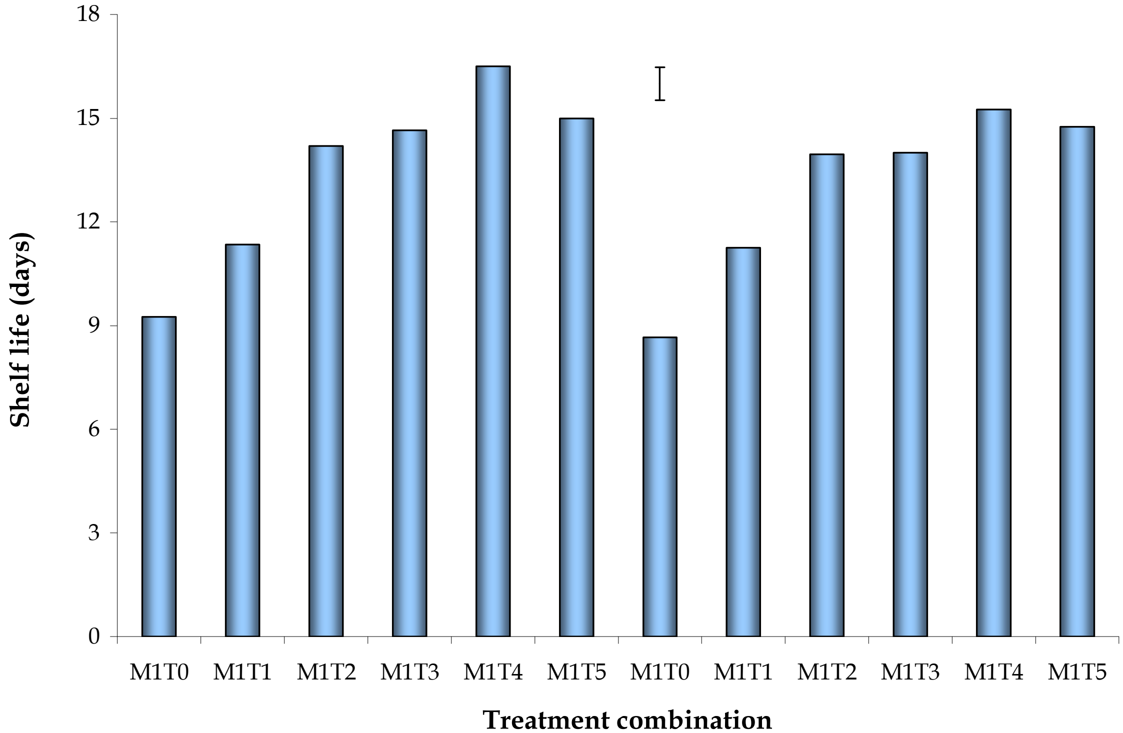

Fig. 8. Combined effect of maturity stages and non-chemical treatments on shelf life of papaya during storage. The vertical bar represents LSD at 5% level of probability. M_1 = Maturity stage 1 (Mature green colour), M_2 = Maturity stage 2 (0-10% yellowing), T_0 = Control or untreated fruits, T_1 = Hot water treatment @ 50°C for 10 minutes, T_2 = Gamma irradiation @ 0.08 kGy for 10 minutes, T_3 = Chitosan coating @ 2%, T_4 = Hot water + gamma irradiation, T_5 = Hot water + chitosan coating.

Conclusion

From the experimental results and discussion, it can be concluded that combined application of hot water and low dose gamma irradiation, followed by hot water and chitosan coating under both maturity stages found to be better in respect of reducing fungal infection, extension of shelf life and quality of papaya.

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