sciendo

Journal of Horticultural Research 2023, vol. 31(1): 35–46
DOI: 10.2478/johr-2023-0021

IMPACT OF MATURITY STAGES, SHRINK-WRAP PACKAGING AND STORAGE TEMPERATURE ON SHELF LIFE AND QUALITY OF PINEAPPLE (*ANANAS COMOSUS* (L.) MERR.) FRUIT 'MAURITIUS'

Saji GOMEZ*, Karishma SEBASTIAN, Chandran ANJALI,
Meagle JOSEPH, Paleeran Kanakan MANEESHA
Kerala Agricultural University, India

Received: August 2022; Accepted: December 2022

ABSTRACT

Pineapple is widely grown in tropical countries, and the fruits are well-known for their unique flavor. The ideal stage of maturity, optimum storage temperature, congenial relative humidity, and adequate type of packaging are critical factors that determine the shelf life and quality of pineapple fruits. Therefore, this investigation was carried out to determine the effect of maturity stage and shrink-wrap packaging, along with ambient and low-temperature storage in order to determine the impact of these factors on extending the shelf life and quality of pineapple fruits. The results revealed that fruits with 75% yellow tubercles at the harvesting stored under ambient temperature had a shelf life of just 7 days compared to the fruits having 25% yellow tubercles subjected to shrink-wrap packaging, followed by low-temperature storage, which had a shelf life of 49 days. The findings of this study conclusively proved that harvesting pineapple fruits with 25% of yellow tubercles, followed by shrink-wrap packaging in 25 μ polyolefin film and subsequent storage in a cool chamber at 12–13 °C and 85% relative humidity can prolong the shelf life and will also maintain the quality of pineapple fruits.

Key words: ascorbic acid, firmness, pineapple, respiration, shelf life

INTRODUCTION

Though pineapple (*Ananas comosus* (L.) Merr.), a member of the Bromeliaceae family, is a commercial fruit crop of the tropics, it is relished by consumers across the globe. The fruit is well-known for its unique, pleasant flavor, which is attributed to the distinct blend of sugars and organic acids. It is a good source of vitamin C, carotenoids, flavonoids, and minerals like potassium, calcium, magnesium, and iron. The proteolytic enzyme bromelain present in the fruit is known for its digestion-stimulating properties. Pineapple is believed to have originated in Brazil and Paraguay, but it has now spread to every tropical region of the world. India is ranked sixth in the global production of pineapple (FAO 2012) and the major producers are Brazil, the Philippines, Costa Rica, Thailand, and China. India's production of pineapple is estimated at 1.79 million tons, with a productivity of 16.83 tons per hectare (NHB 2020). In India, the plant is mainly grown in the Southern and North-Eastern states.

The South Indian state of Kerala is one of the leading producers of pineapple in the country. The predominant cultivar in the state is 'Mauritius', which occupies more than 90% area under cultivation. Cultivars 'Kew' and 'MD-2' are also grown on a smaller scale. Pineapple is grown throughout the year owing to the humid tropical climate prevailing in the state. However, bumper harvest often leads to market gluts, leading to extreme price fluctuations and the growers being deprived of remunerative prices for the produce. Postharvest losses of pineapple to the tune of 20–30% have been reported in the state. Besides, ambiguity on the right stage of harvesting pineapple remains unclear even today. Consumers normally judge the maturity of pineapples by their color and aroma. It is recommended to have a sugar: acid ratio of 0.9 to 1.3 (Soler 1992). Being nonclimacteric, fruits when harvested at immature stages will not continue to ripen and, therefore, will not attain their full flavor during marketing. Pineapple fruit contains a thick, thorny, inedible peel and a large crown, which pose difficulties in postharvest handling, transportation, and marketing.

*Corresponding author
e-mail: saji.gomez@kau.in

Besides, the high perishability of the fruit is another reason for the huge postharvest losses. Information regarding optimum conditions of storage, ideal packaging requirements, and physiological and biochemical activities of pineapple fruits is scanty. Joseph-Adekunle et al. (2009) stored physiologically mature pineapple procured from farmers' fields in Nigeria, for 40 days under three conditions, viz., refrigeration (10 °C), ambient storage (27 °C), and under intense sunlight (37 °C). The study revealed that spoilage of fruits commenced as early as the third day under ambient and intense sunlight conditions. They also reported that deterioration of the fruits could be delayed up to 15 days of storage and that the shelf life of the fruits could be prolonged to 33 days under refrigerated storage. Polyolefin films are well-known for their toughness and good tensile strength, in addition to their abrasion resistance and chemical resistance properties. Sudhakar Rao and Shivashankara (2015) subjected freshly harvested mature green mangoes to individual shrink-wrapping using two semipermeable Cryovac films (D-955 and LD-935) and an LDPE film. They reported that shrink-wrapped mangoes can be stored for 5 weeks at 8 °C when packaged in D-955 (15 μ thickness) film. The losses in the mass of fruits of 'Banganapalli' and 'Alphonso' were only 0.5% and 1.4%, respectively, after storage. However, studies on the effect of individual shrink-wrapping and types of polyethylene films used for packaging pineapple are very limited. This may be due to the unique shape and structure of the fruit, which is marketed along with the crown, which might pose a hindrance in packaging into convenient containers during long-distance transportation. Therefore, the present investigation was carried out in 2019–2020 to find out the optimal stage of maturity for harvesting, the effect of shrink-wrap packaging and storage temperature on extending the shelf life and maintaining the quality of 'Mauritius' pineapple fruit.

MATERIALS AND METHODS

Postharvest handling

Pineapple 'Mauritius' fruits were harvested at three maturity stages, i.e., 25, 50, and 75% of tubercles turned yellow. Fruits with around 75% tubercles turning yellow are normally sold in retail markets, and those with 25 to 50 yellow tubercles are transported to wholesale markets from where fruits are further transported to retail markets or consumer outlets depending upon the extent of coloration of tubercles. These fruits were harvested from farmers' fields in the Ernakulam district of Kerala, a prominent pineapple-growing belt in the state. Harvested fruits were quickly transported to the Department of Post Harvest Technology, College of Agriculture, in plastic crates. The fruits were sorted to remove the deformed and damaged ones, followed by a dry brushing of the thick rind to remove adhering dirt and dust. The stalk of the fruits was clipped to retain a 1-cm stalk length. These fruits were subsequently precooled at 12–13 °C, for 8 hours. This was followed by overwrapping each fruit loosely with polyolefin film of 25 μ thickness with an impulse sealer and then passing it through the tunnel of a shrink-wrapping machine maintained at 120 °C for 10 seconds, resulting in individual pineapple fruits being tightly wrapped with the polyolefin film. The shrink-wrapped fruits, along with the unwrapped samples in the three maturity stages, were subsequently held under two storage conditions, viz., ambient temperature of 30–32 °C (maximum) and 18–20 °C (minimum) with 80–90% relative humidity (RH) and also, in a cool chamber (12–13 °C and 85–90% RH). The experiment consisted of twelve treatments, viz., T_1 – unwrapped fruits with 75% of eyes having yellow color, stored at ambient temperature (control – ambient temperature); T_2 – unwrapped fruits with 75% of eyes having yellow color, stored in cool chamber (control – cool chamber); T_3 – shrink-wrapped fruits with 75% of eyes having yellow color, stored at ambient temperature; T_4 – shrink-wrapped fruits with 75% of eyes having yellow color, stored in a cool chamber; T_5 – unwrapped fruits with 50% of eyes having yellow color, stored at ambient temperature (control – ambient temperature); T_6 – unwrapped fruits with 50% of eyes having yellow color, stored in a cool chamber (control – cool chamber); T_7 – shrink-wrapped fruits with 50% of eyes having yellow color, stored at ambient temperature; T_8 – shrink-wrapped fruits with 50% of eyes having yellow color, stored in a cool chamber; T_9 – unwrapped fruits with 25% of eyes having yellow color, stored at ambient temperature (control – ambient temperature); T_{10} – unwrapped fruits with 25% of eyes having yellow color, stored in a cool chamber (control – cool chamber); T_{11} – shrink-wrapped fruits with 25% of eyes having yellow color, stored at ambient temperature; T_{12} – shrink-wrapped fruits with 25% of eyes having yellow color, stored in a cool chamber. Observations on titratable acidity, ascorbic acid, loss in weight, shelf life, rate of respiration, firmness, and total soluble solids (TSS) were recorded at weekly intervals. The various treatments, stages of maturity at harvest, and storage conditions are presented in Table 1.

Quality characteristics

Firmness

The firmness of fruits during storage was determined by a digital fruit firmness tester (Vaiseshika, 6003E, India), after removing a slice of the rind of the fruit along with a thin portion of the pulp, followed by insertion of the plunger of the tester into the fruit. The diameter and the speed of the cylindrical plunger were 8 mm and 100 mm per minute. The values were expressed as the force required (in kg) to complete penetration (1 cm).

Weight loss

The loss in weight was calculated as a cumulative percent loss in weight from the initial fruit weight before storage and the loss in weight recorded on the day of observation during storage under ambient and cool-chamber conditions.

Respiration rate

The rate of respiration was determined by using an oxygen/carbon dioxide analyzer (Dansensor, CheckPoint O_2/CO_2, Denmark). The experimental setup consisted of the gas analyzer, a flow meter, and an airtight container (respiratory jar) with two valves that contained the samples. Three replicates (fruits) of each treatment were taken after the removal of the polyolefin film, followed by incubation in the respiratory jars for ≤ 2 h, after which a sample of the headspace gas was drawn with a needle and injected into the gas analyzer. The samples were incubated at their storage temperature, viz., ambient (30 ± 2 °C) and the cool chamber (12–13 °C), and the measurements were done at ambient temperature as the operating temperature of the gas analyzer used was in the range of 0 to 40 °C. A digital display provided the level of carbon dioxide liberated by the samples, and the values were noted till the displayed values became stable. The respiratory rates were expressed in ml of CO_2 liberated by the fruits per kilogram per hour (Gomez et al. 2003).

Shelf life

The shelf life of pineapple was assessed taking into account the decrease in firmness, beyond which the fruit cannot be marketed (not lower than 0.4 kg·cm^{-2}). In addition to fruit firmness, fruit decay, physicochemical parameters, and days from harvest to maximum edible quality were also considered (Mandal et al. 2015). The temperature and RH of the ambient storage were 30–32 °C (maximum) and 18–20 °C (minimum) with 80–90% RH and that of the cool chamber were 12–13 °C and 85–90% RH, respectively. A shelf-life assessment was done at weekly intervals for all the treatments.

Total soluble solids

Estimation of TSS was done by a digital refractometer (Atago, PAL-1, PAL-2, Japan) and the results were expressed in percent degree Brix.

Titratable acidity

The titratable acidity of the fruits was estimated by titrating a known weight of the sample against 0.1 N NaOH solution using phenolphthalein as an indicator. The acidity was calculated and expressed as percent citric acid (AOAC 1998).

Ascorbic acid

Ascorbic acid was determined by titrating the known weight of the sample with 2,6-dichlorophenolindophenol dye, using metaphosphoric acid as stabilizing agent (AOAC 1998).

Table 1. Stage of maturity, storage conditions, and packaging of pineapple fruits 'Mauritius'

Treatments	Maturity stage (color)	Temperature and RH	Packaging
T_1	75% tubercles with yellow color	ambient temperature (AT) 30–32 °C; 80–90%	UW
T_2	75% tubercles with yellow color	cool chamber (CC) 12–13 °C; 85–90%	UW
T_3	75% tubercles with yellow color	30–32 °C; 80–90% (AT)	SW
T_4	75% tubercles with yellow color	12–13 °C; 85–90% (CC)	SW
T_5	50% of eyes having yellow color	30–32 °C; 80–90% (AT)	UW
T_6	50% tubercles with yellow color	12–13 °C; 85–90% (CC)	UW
T_7	50% of eyes having yellow color	30–32 °C; 80–90% (AT)	SW
T_8	50% tubercles with yellow color	12–13 °C; 85–90% (CC)	SW
T_9	25% tubercles with yellow color	30–32 °C; 80–90% (AT)	UW
T_{10}	25% tubercles with yellow color	12–13 °C; 85–90% (CC)	UW
T_{11}	25% tubercles with yellow color	30–32 °C; 80–90% (AT)	SW
T_{12}	25% tubercles with yellow color	12–13 °C; 85–90% (CC)	SW

AT – ambient temperature; CC – cool chamber; UW – unwrapped; SW – shrink-wrapped

Statistical analysis

The experiment was repeated twice and three replicates were taken for testing each quality parameter. Each replication consisted of ten fruits. Observations on physiological parameters like weight loss, respiration, firmness, TSS, titratable acidity, ascorbic acid, and shelf life were recorded at weekly intervals. The total duration of the experiment was 49 days. The data was expressed on the basis of mean and standard deviation. A two-way analysis of variance (ANOVA) was conducted using a completely randomized design to arrive at the impact of maturity stages and shrink-wrap packaging on the shelf life and quality of pineapple fruits during storage.

RESULTS AND DISCUSSION

Firmness

Cell wall degradation during ripening is a result of the action of enzymes like polygalacturonase, pectin methyl esterase, and cellulose. Measurements of fruit firmness indicated hardness or softness and is also an indirect indicator of the shelf life of fruits. Initial firmness of fruits with 25, 50, and 75% yellow tubercles were 0.84, 0.78, and 0.57 $kg \cdot cm^{-2}$, respectively (Fig. 1). Othman (2008) and Mandal et al. (2015) described that the firmness of fruits declined as they matured. Fruit firmness in our experiment showed a declining trend in all the treatments during storage. The most stable firmness values up to 7 weeks of storage were recorded in fruits of the lowest maturing stage during harvest and cold stored, especially in those fruits that were also foil wrapped. After one week, the firmness decreased most rapidly in fruits harvested at the stage of 75% and 50% yellow tubercles and ambient-stored. Fruits harvested at the stage of 75% yellow tubercles lost their firmness the slowest when they were stored in cold. Among all the treatments, shrink-wrapped fruits with 25% yellow tubercles held in a cool chamber had the highest firmness till the end of storage (more than 6 $kg \cdot cm^{-2}$). The less ripeness of fruits intended for storage means that they have to go through more transformations to change their firmness, so it takes longer. Storage of fruits at lower temperatures might have slowed down the rate of biochemical reactions leading to higher firmness in fruits held in a cool chamber. Shrink-wrap packaging might have resulted in the modification of atmospheric gases surrounding the fruits leading to reduced respiratory activity. Atmospheric modification of the shrink-wrapped fruits occurs as a result of the inherent respiratory activity of the fruits coupled with the selective permeability of the polyolefin film to atmospheric gases, particularly O_2 and CO_2. Similar results on better retention of firmness of the 'Neelum' mango as a result of shrink-wrap packaging were reported by Gomez et al. (2021).

Weight loss

Loss in the weight of fruits during storage is an indication of the metabolic activity of fruits during their postharvest handling period, which has a direct bearing on their shelf life. Loss in weight occurs as a result of respiration and the transpiration of moisture through the skin of fruits. A gradual weight loss was recorded in all the treatments during storage (Fig. 2). Fruits harvested with 25% yellow tubercles held in a cool chamber recorded significantly lower weight loss throughout storage. Further, fruits with 25% yellow tubercles subjected to shrink-wrapping and subsequently held in the cool chamber, recorded the lowest weight loss among all the treatments during the entire storage period. Significantly lower weight loss in fruits stored in the cool chamber at all maturity stages compared to those held under ambient conditions may be due to a reduction in metabolic activities as a result of the temperature of 12 to 13 °C and 85 to 90% RH. The lowest weight loss in shrink-wrapped fruits held in cool chambers may be due to the modification of atmospheric gases surrounding the fruit, leading to reduced respiratory activity in these fruits. Paull and Chen (2014) reported a storage temperature of 7 to 12 °C and an RH of 85 to 95% as ideal for the storage of pineapple fruit at the color break stage. Kamol et al. (2014) reported that the maximum weight loss of 19.135% was recorded in the control fruits of pineapple 'Giant Kew' and the minimum (3.42%) in nonperforated polyethylene bags on the eighteenth day of storage.

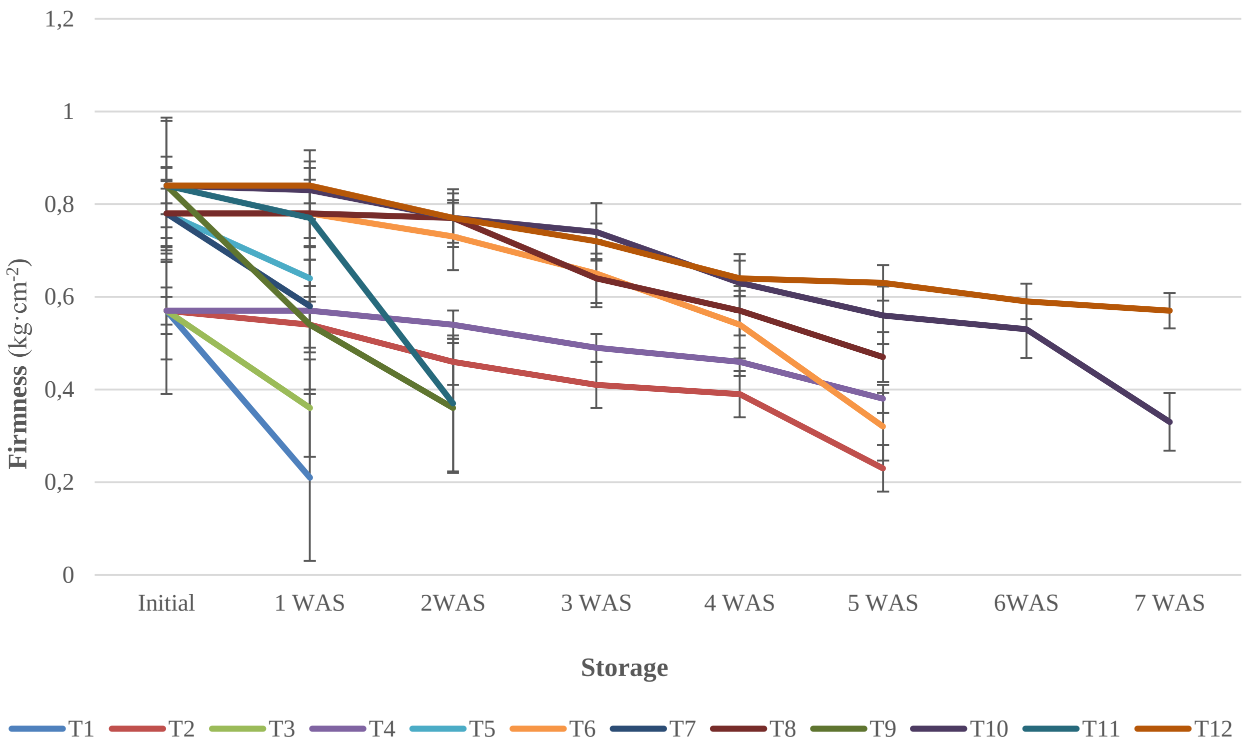

Figure 1. Effect of maturity stage, shrink-wrap packaging, and storage temperature on firmness (kg·cm^{-2}) of pineapple

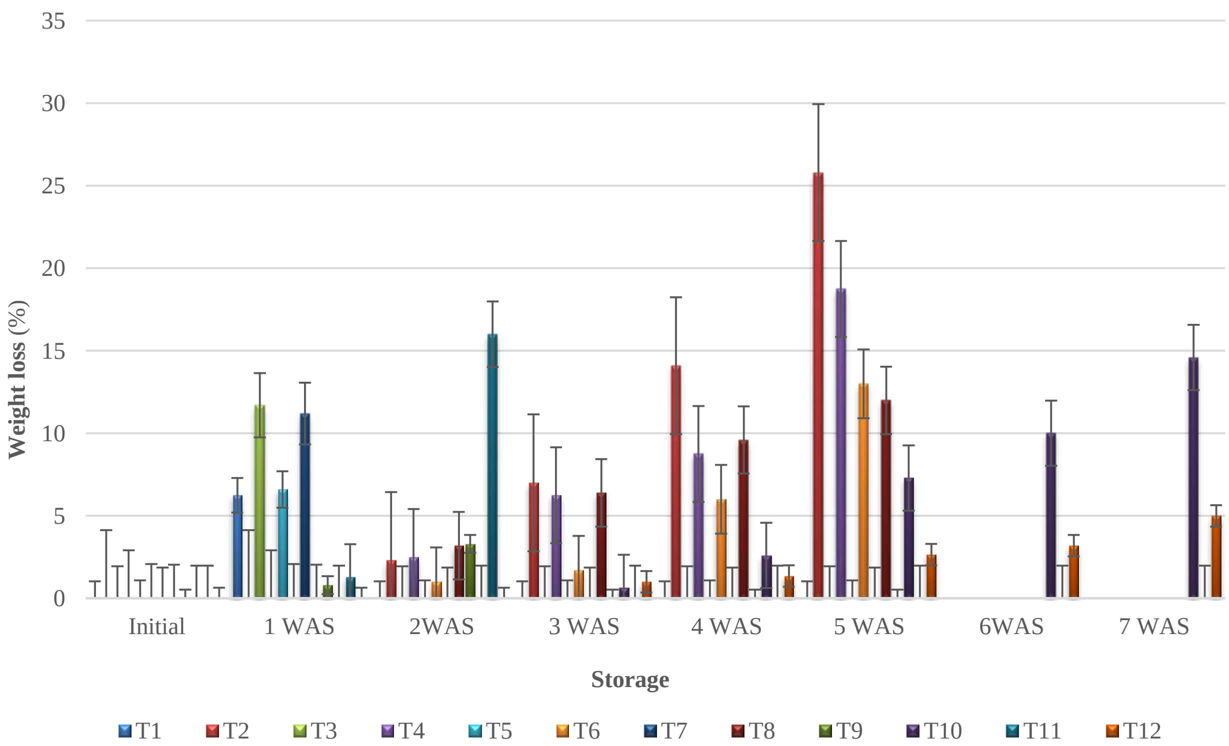

Figure 2. Effect of maturity stage, shrink-wrap packaging, and storage temperature on weight loss (%) of pineapple

Respiration rate

Respiration is a catabolic process in which reserve photosynthates are used up. Unhindered respiration will detrimentally affect the quality and shelf life of fruits. CO_2 could not be detected in the headspace of fruits with 25% yellow tubercles at the beginning of storage, whereas fruits with 50% and 75% yellow tubercles had 1.0 and 2.0 $ml \cdot kg^{-1} \cdot h^{-1}$ CO_2 in the headspace, respectively. The respiratory activity of pineapple recorded a gradual rise in all the treatments (Fig. 3). Unlike climacteric fruits, pineapple being a non-climacteric fruit, no respiratory peak was observed in any of the treatments, irrespective of maturity stage and storage temperature. However, fruits stored in a cool chamber recorded significantly lower respiration rates compared to the ones stored under ambient conditions. Unwrapped fruits with 75% and 50% yellow tubercles held under ambient conditions (T1 and T5) became unmarketable after 1 week of storage due to senescence. Both unwrapped and wrapped fruits with 50% yellow tubercles (T6 and T8) and unwrapped samples with 75% yellow tubercles (T2) kept in a cool chamber remained marketable for up to 6 weeks. Even though shrink-wrapping reduced respiratory activity at low temperature, the storage of wrapped fruits with 75% and 50% yellow tubercles (T3 and T7) under ambient conditions became unmarketable after 1 week due to fungal decay as a result of condensation of moisture inside the package. Similarly, unwrapped and wrapped fruits with 25% yellow tubercles (T9 and T11) stored under ambient conditions became unmarketable after 2 weeks due to spoilage. Stage of maturity and shrink-wrap packaging along with low-temperature storage significantly reduced the respiratory activity of fruits. Fruits with 25% yellow tubercles, subjected to shrink-wrap packaging and subsequently stored in a cool chamber, recorded the lowest respiratory activity throughout storage. After 7 weeks of storage, the unwrapped (T10) and shrink-wrapped fruits (T12) with 25% yellow tubercles held in a cool chamber showed respiratory rates of 18.0 and 7.0 $ml \cdot kg^{-1} \cdot h^{-1}$ CO_2, respectively. Lower rates of respiration in the wrapped fruits held in a cool chamber may be due to the combined effects of atmosphere modification and reduced metabolic activity at low temperatures. Shrink-wrap packaging may have retarded the respiratory activity of fruits due to a reduction in O_2 concentration and an increase in CO_2 levels surrounding the fruits as a result of atmosphere modification. Similar results were obtained in the mango 'Neelum' when subjected to shrink-wrap packaging, followed by storage in a cool chamber (Gomez et al. 2021). Polyethylene bagging on individual pineapple fruit resulted in an atmospheric composition of 8–10% O_2 and 7% CO_2 (Abdullah et al. 1985; Rohrbach & Paull 1982). Yahia (1998) recommended 2–5% O_2 and 5–10% CO_2 as the ideal atmospheric gas composition for pineapple fruits. Paull and Chen (2014) reported that the rate of respiration of pineapple rose exponentially with a rise in storage temperature. They found that the respiratory rate of pineapple was 2, 4–7, 10–16, and 19–29 mg $CO_2 \cdot kg^{-1} \cdot h^{-1}$ at 5, 10, 15, and 20 °C, respectively.

Shelf life

Postharvest handling techniques have a considerable impact on the shelf life of fruits. Packaging with polymeric films and subsequent storage at ideal temperatures and humidity have a direct bearing on the shelf life of fruits. Sudhakar Rao and Shivashankara (2015) reported that shrink-wrapping of mango 'Alphonso' and 'Banganapalli' with Cryovac film (D-955, 15 µ thickness), followed by storage at 8 °C could extend the shelf life of the fruits by 5 weeks. In the present study, the most important in the length of shelf life was storage temperature (Fig. 4). Fruits stored at ambient temperature were marketable for about 7 days when harvested at the stage of 75% and 50% of yellow tubercles and about 14 days when had 25% of yellow tubercles, whereas shelf life of fruits stored in cold was 3, 4, and 6–7 weeks, respectively. The wrapping was significantly beneficial only for fruits harvested at the stage of 25% of yellow tubercles. The shelf life was longer for fruits harvested at the stage of 50 and 25% of yellow tubercles. Maximum shelf life of 7 weeks was recorded in fruits harvested with 25% yellow tubercles, followed by shrink-wrapping and subsequently held in the cool chamber at 12–13 °C and 85–90% RH (T12). The extension of the shelf life of fruits as indicated by the maturity stage and low-temperature storage may be due to the retardation of respiratory activity of fruits induced by the reduction in CO_2 levels and increase in O_2 concentration surrounding the fruit.

Low-temperature storage may have further slowed down the biochemical reactions, which resulted in extended shelf life. Further, fruits with 25% yellow tubercles might have had slower rates of ripening and senescence. Dhar et al. (2008) reported the shelf life of the pineapple 'Giant Kew' could be extended to 21 days when harvested 14 days before optimum maturity. In another study, pineapple when held at temperatures of 7 to 12 °C had a storage life of 14 to 20 days, when harvested with 25% yellow tubercles. Besides, the treatments were considered unmarketable when the fruit firmness showed values less than 0.1 $kg \cdot cm^{-2}$. Similar values were also taken into consideration for determining the shelf life of the pineapple fruit 'Giant Kew' (Mandal et al. 2015).

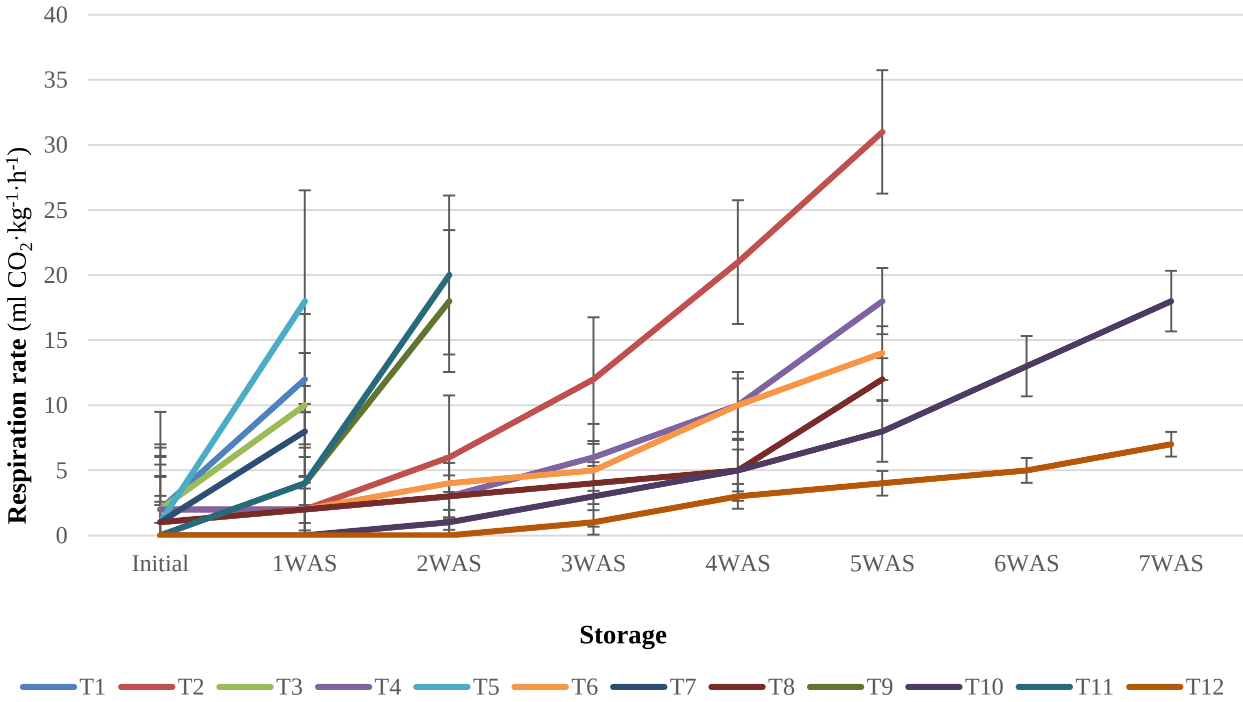

Figure 3. Effect of maturity stage, shrink-wrap packaging, and storage temperature on respiration rate (ml $CO_2 \cdot kg^{-1} \cdot h^{-1}$) of pineapple

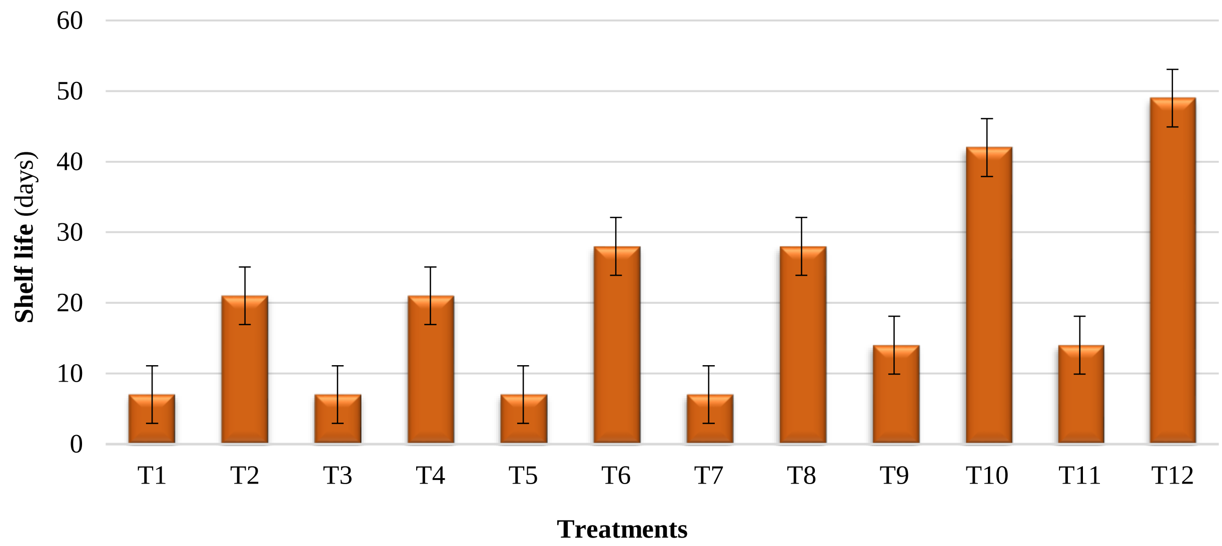

Figure 4. Effect of maturity stage, shrink-wrap packaging, and storage temperature on shelf life (days) of pineapple

Total soluble solids

The flavor of fruits is considerably influenced by TSS, which along with aroma are the most important factors responsible for consumer acceptability. In the present study, TSS significantly varied with maturity stages. Fruits with 25, 50, and 75% of yellow tubercles had initial TSS contents of 4.0, 7.0, and 9.0°Brix, respectively (Fig. 5). Higher TSS in pineapple fruits with 75% yellow tubercles may be due to higher levels of simple sugars like glucose and fructose and also, due to lower levels of organic acids. Higher levels of TSS in a pineapple with the advancement of maturity were reported by Dhar et al. (2008). In the present study, the TSS content of pineapple fruits increased throughout storage, irrespective of the treatments adopted. The rise in TSS during storage may be due to the initial hydrolysis of starch into disaccharide sucrose and further into simple sugars by the enzyme amylase and invertase, respectively. Here, the TSS content of pineapple fruits was independent of the maturity stage, which was significantly influenced by the storage temperature, and less by the shrink-wrap packaging. In the first week, fruits stored under ambient conditions had higher TSS than those held at low temperatures. This might be due to faster rates of biochemical reactions at higher temperatures. Shrink-wrap packaging of pineapple fruits followed by storage at low temperatures resulted in lower levels of TSS in these fruits. The same trend continued until the end of the storage period. Kumara and Hettige (2020) reported that the highest TSS content of 17.75 ± 0.67 was seen in the 100% yellow tubercles stage in the pineapple 'Mauritius'.

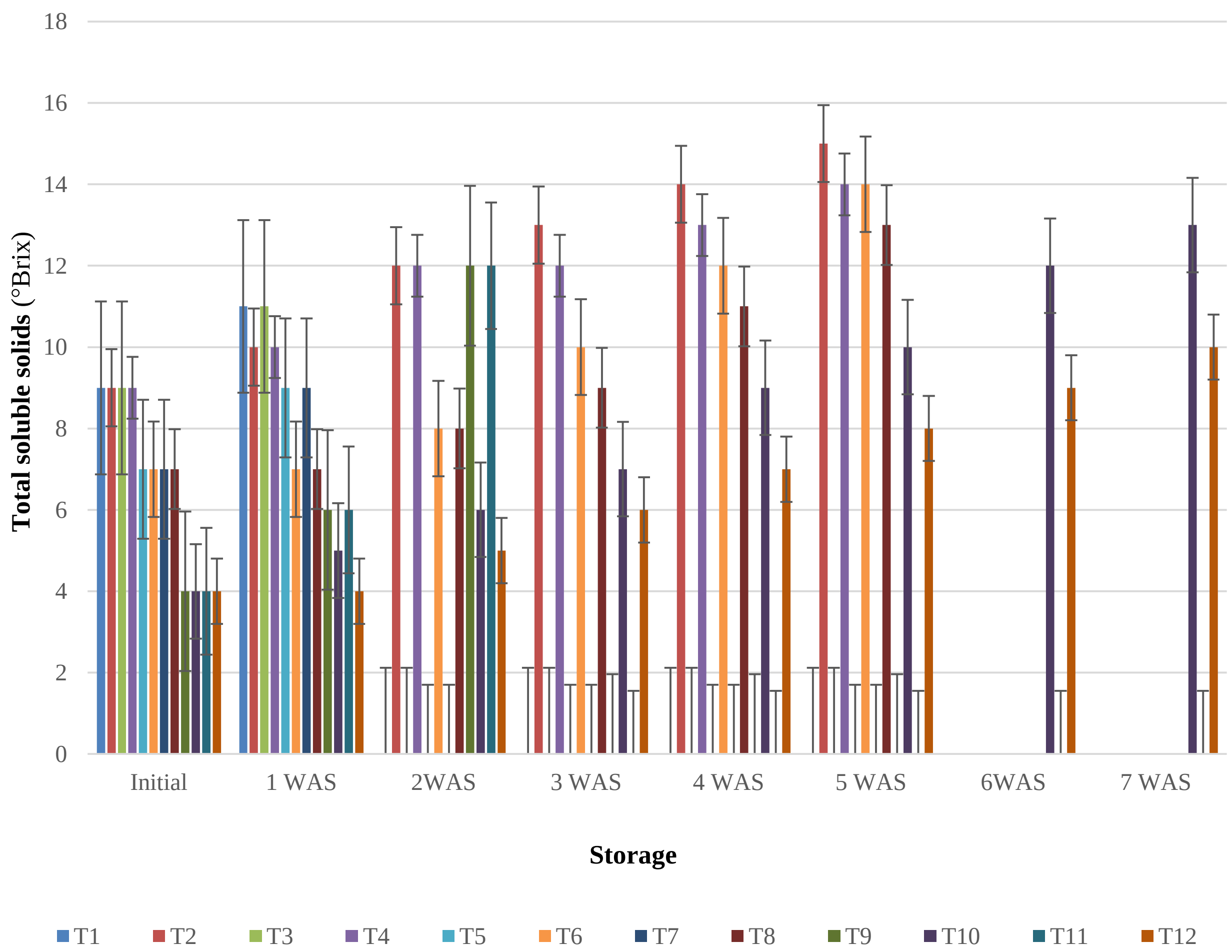

Figure 5. Effect of maturity stage, shrink-wrap packaging, and storage temperature on total soluble solids (°Brix) of pineapple

Titratable acidity

Organic acids, along with sugars have a prominent role in contributing to the flavor of fruits. Fruits with lower organic acids are preferred by consumers. The titratable acidity of pineapple differed significantly with maturity stages. Fruits with 25, 50, and 75% yellow tubercles had titratable acidity levels of 0.89, 0.76, and 0.64%, respectively (Fig. 6). The organic acids content in fruits generally shows a declining trend as maturity progresses. In the present experiment, the acidity of fruits fell during storage, irrespective of maturity stage and storage temperature, and this situation was observed in our experiment. Kamol et al. (2014) reported that premature and optimum mature pineapple fruits of the 'Giant Kew' contained titratable acidity of 0.77% and 0.68%, respectively. The fall in the acidity of pineapple fruits during storage may be due to their utilization in the respiratory process. A similar pattern of decline in acidity was reported by Siti Rashima et al. (2019) in three different cultivars of pineapple grown in Malaysia, which confirms the findings of the present study. However, this report contradicts the findings of Dhar et al. (2008) who reported an increase in the acidity of pineapple as fruits developed. Next to the maturity stage at harvest, storage temperature had significant effects on the titratable acidity of pineapple fruits after 1 week of storage. Fruits held in cool chambers retained higher levels of acidity than those stored under ambient conditions. After 7 weeks of storage, shrink-wrapped fruits with 25% yellow tubercles held in a cool chamber recorded titratable acidity of 0.36%. Low-temperature storage may have retarded the rate of respiratory activity of fruits held in a cool chamber. Retention of higher acidity (0.97%) in polyethylene-packed mango 'Chaunsa' was reported by Rathore et al. (2010) as compared to the unwrapped fruits (0.44%).

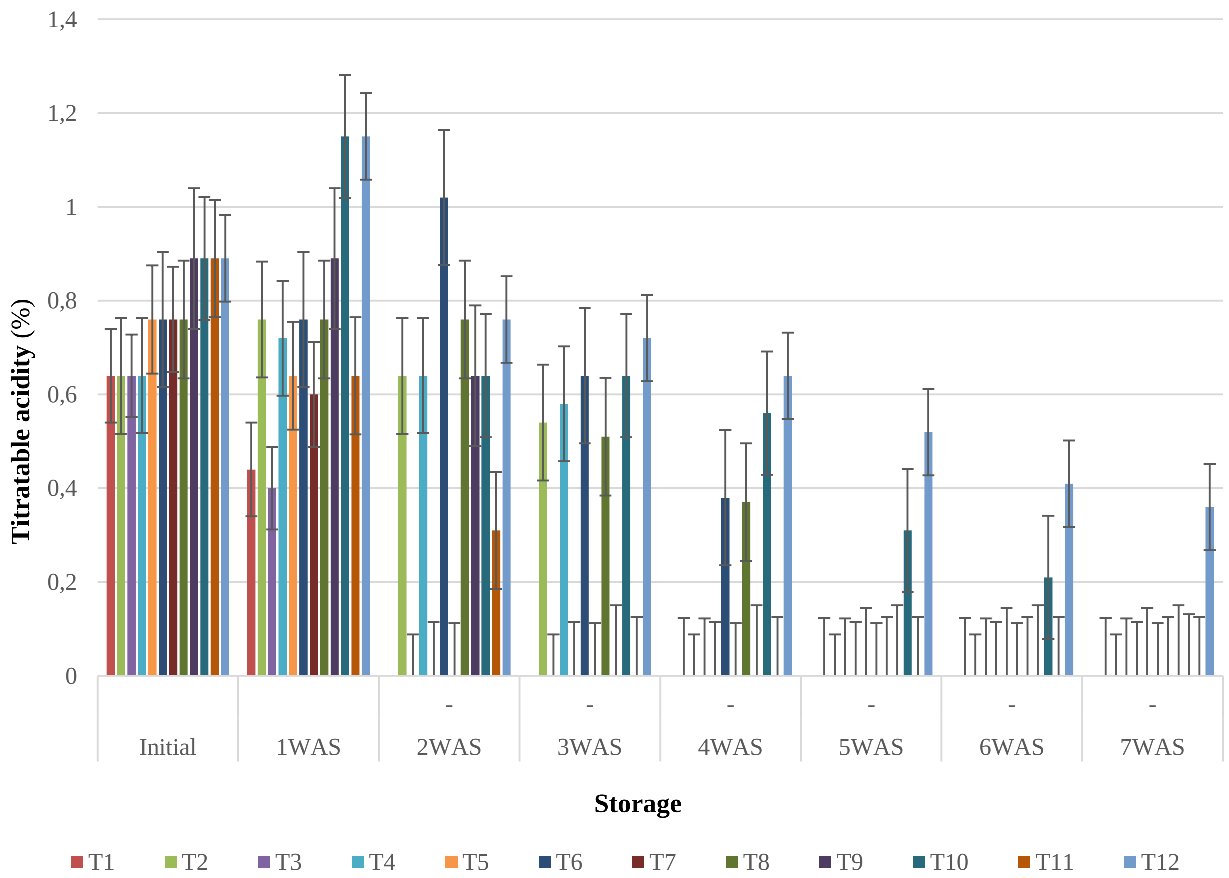

Figure 6. Effect of maturity stage, shrink-wrap packaging, and storage temperature on titratable acidity (%) of pineapple

Ascorbic acid

Vitamin C is known for its antioxidant properties as well as for its immunity-boosting activity. Fruits with high levels of ascorbic acid are often valued for their nutritive quality and also, form essential ingredients in formulating healthy and balanced diets. The ascorbic acid content of pineapple varied significantly with maturity stages and its content decreased with maturity (Fig. 7). The initial ascorbic acid content of pineapple fruits with 25, 50, and 75% yellow tubercles was 46.8, 36.4, and 31.2 mg·100 g^{-1}. Mandal et al. (2015) reported an ascorbic acid content in the range of 18.86 to 23.14 mg·100 g^{-1} in the 'Giant Kew'. Ascorbic acid content declined with progress in ripening. After 1 week of storage, fruits with 25% yellow tubercles held in a cool chamber, irrespective of the packaging had the maximum ascorbic acid content of 48.8 mg while the lowest (26.0 mg·100 g^{-1}) was seen in the fruits with 75% yellow tubercles stored under ambient conditions. Ascorbic acid is prone to oxidative degradation, and holding the fruits at high temperatures has also been found to result in substantial losses of this vital nutrient. The fall in the ascorbic acid content of pineapple during storage might be due to its conversion to dehydroascorbic acid by the action of the enzyme ascorbic acid dehydrogenase. The maturity stage, storage temperature, and packaging significantly affected the ascorbic acid content in pineapple. Towards the end of storage (after 6 weeks), fruits with 25% yellow tubercles subjected to shrink-wrapping and subsequently held in a cool chamber retained the highest ascorbic acid content (23.7 mg), followed by the unwrapped fruits in the same storage condition (12.0 mg·100 g^{-1}). Similar observations were also reported by Kamol et al. (2014) wherein pineapple fruits of the cultivar 'Giant Kew' at the premature stage had higher levels of ascorbic acid than the fruits of optimum maturity, and the ascorbic acid content of fruits declined throughout storage, irrespective of maturity stage and duration of storage. Hossain et al. (2018) also reported that the vitamin C content of the 'Kew' pineapple declined from 21.33 ± 0.88 to 8.66 ± 0.66 mg·100 g^{-1}, and that of the 'MD-2' from 95.33 ± 2.40 to 34.66 ± 3.53 mg·100 g^{-1} during 9 days of storage under ambient conditions.

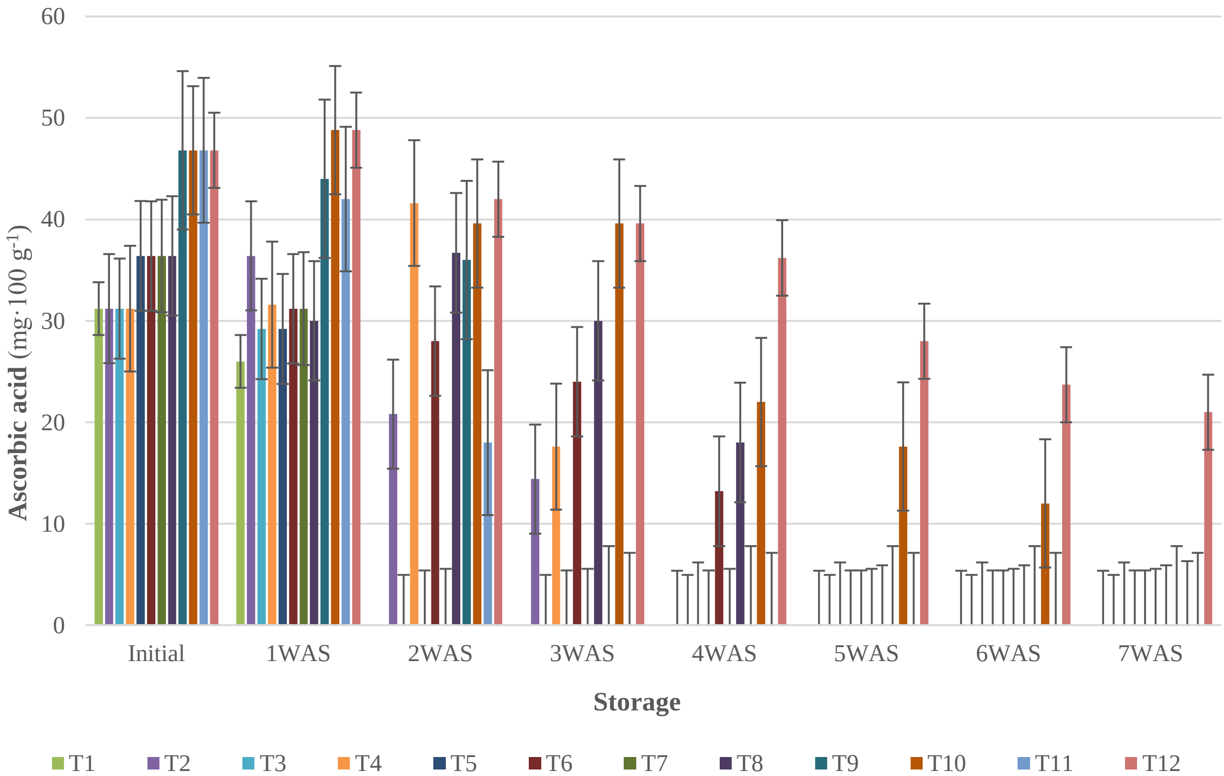

Figure 7. Effect of maturity stage, shrink-wrap packaging, and storage temperature on ascorbic acid content (mg·100 g^{-1}) of pineapple

Limitations

The research has some limitations, which we encountered during the course of the study. As the response of the fruits to harvest maturity, shrink-wrapping, and storage temperature was highly variable; uniformity with regard to the duration of the experiment, the shelf life, and quality parameters could not be attained. This resulted in considerable complexity in the interpretation of data as well as the statistical analysis. However, a completely randomized design was found to be the most appropriate for this experiment. As some treatments resulted in unmarketable fruits during the course of the experiment, data for these treatments are lacking and this makes the interpretation of the results more complex.

CONCLUSION

The study proved that the shelf life and quality of pineapple fruits can be significantly improved by harvesting the fruits at the correct maturity stage in combination with ideal packaging and appropriate storage conditions. Fruits harvested with 25% yellow tubercles and subjected to shrink-wrapping, followed by storage in a cool chamber maintained at 12–13 °C and 85–90% RH, could be stored for up to 7 weeks. Also, fruit quality attributes like TSS, vitamin C, respiration, firmness, and fruit weight could be improved considerably by proper storage conditions. The protocol applied in the present study could pave way for future prospects in postharvest handling and long-distance transportation of pineapple fruits.

Acknowledgments

The study was carried out with the funds received from the Kerala State Planning Board through the Directorate of Research, Kerala Agricultural University (Grant No. R8/64430/2019).

Conflict of interest

The authors who participated in the study do not have any conflict of interest.

REFERENCES

Abdullah H., Rohaya M.A., Zaipun M.Z. 1985. Effect of modified atmosphere on black heart development and ascorbic acid contents in ‘Mauritius’ pineapples (*Ananas comosus* cv. ‘Mauritius’) during storage at low temperature. ASEAN Food Journal 1(1–2): 15–18.

AOAC 1998. Official methods of analysis, 16th ed. Association of Official Analytical Chemists, USA, 899 p.

Dhar M., Rahman S.M., Sayem S.M. 2008. Maturity and post harvest study of pineapple with quality and shelf life under red soil. International Journal of Sustainable Crop Production 3(2): 69–75.

FAO 2012. The state of food and agriculture. Investing in agriculture for a better future. Food and Agriculture Organization of the United Nations. https://www.fao.org/3/i3028e/i3028e.pdf

Gomez S., Roy S.K, Pal R.K. 2003. Primary processing of fenugreek (*Trigonella foenum graecum* L.) – An eco-friendly approach for convenience and quality. Plant Foods for Human Nutrition 58(3): 1–10. DOI: 10.1023/b:qual.0000040366.42996.1f.

Gomez S., Jacob S., Joseph M.., Johnson D., Sebastian K. 2021. Evaluation of surface coating and shrink-wrap packaging on quality and shelf life of mango cultivar ‘Neelum’. Plant Science Today 8(3): 545–551. DOI: 10.14719/pst.2021.8.3.1192.

Hossain M.M., Zhimomi T., Nupani P.S., Singh A.K. 2018. Studies on changes in physico-chemical parameters of pineapple fruits of cultivars Kew and MD-2 during storage at ambient temperature. International Journal of Current Microbiological and Applied Sciences 7(6): 891–899. DOI: 10.20546/ijcmas.2018.706.105.

Joseph-Adekunle T.T., Okelana M.A., Adekoya I.A. 2009. Storage of pineapple fruits under different conditions: Implication on shelf life. Nigerian Journal of Horticultural Science 14(1): 76–82. DOI: 10.4314/njhs.v14i1.62161.

Kamol S.I, Howlader J., Sutra Dhar G.C., Aklimuzzaman M. 2014. Effect of different stages of maturity and postharvest treatments on quality and storability of pineapple. Journal of Bangladesh Agricultural University 12(2): 251–260. DOI: 10.3329/jbau.v12i2.28679.

Kumara B.A.M.S., Hettige K.D.T. 2020. Ripening stage affects the quality of fresh and dehydrated pineapples (*Ananas comosus* (L.) Merr.) cv. Mauritius in Sri Lanka. Sustainable Food Production 8: 29–37. DOI: 10.18052/www.scipress.com/sfp.8.29.

Mandal D., Lalremruata, Hazarika T.K., Nautiyal B.P. 2015. Effect of post-harvest treatments on quality and shelf life of pineapple (*Ananas comosus* (L.) Merr. 'Giant Kew') fruits at ambient storage condition. International Journal of Bio-resource and Stress Management 6(4): 490–496. DOI: 10.5958/0976-4038.2015.00072.x.

NHB 2020. Annual Report 2020-21. National Horticulture Board. Ministry of Agriculture and Farmers Welfare, Government of India, India. https://nhb.gov.in/pdf/AR-2020-21.pdf

Othman Z. 2008. Effects of postharvest coatings and heat treatment on quality of stored pineapple fruits. Ph.D. Thesis, University of Putra Malaysia. [in Malaysian with English abstract]

Paull R.E, Chen C.C. 2014. Pineapple: Postharvest Quality-Maintenance Guidelines. University of Hawai'i, College of Tropical Agriculture and Human Resources. Fruit, Nut and Beverage Crops. https://www.ctahr.hawaii.edu/oc/freepubs/pdf/F_N-32.pdf

Rathore H.A., Masud T., Sammi S., Majeed S. 2010. Innovative approach of active packaging in cardboard carton and its effects on overall quality attributes such as weight loss, total soluble solids, pH, acidity and ascorbic acid contents of Chaunsa white variety of mango at ambient temperature during storage. Pakistan Journal of Nutrition 9(5): 452–458. DOI: 10.3923/pjn.2010.452.458.

Rohrbach K.G., Paull R.E. 1982. Incidence and severity of chilling induced internal browning of waxed 'Smooth Cayenne' pineapple. Journal of the American Society for Horticultural Science 107(3): 453–457. DOI: 10.21273/jashs.107.3.453.

Siti Rashima R., Maizura M., Wan Nur Hafzan W.M., Hazzeman H. 2019. Physicochemical properties and sensory acceptability of pineapples of different varieties and stages of maturity. Food Research 3(5): 491–500. DOI: 10.26656/fr.2017.3(5).060.

Soler A. 1992. Ananas: Critères de qualité. CIRAD-IRFA, Paris, France, 48 p. [in French]

Sudhakar Rao D.V., Shivashankara K.S. 2015. Individual shrink wrapping extends the storage life and maintains the antioxidants of mango (cvs. 'Alphonso' and 'Banganapalli') stored at 8°C. Journal of Food Science and Technology 52(7): 4351–4359. DOI: 10.1007/s13197-014-1468-6.

Yahia E.M. 1998. Modified and controlled atmospheres for tropical fruits. Horticultural Reviews 22: 123–183. DOI: 10.1002/9780470650738.ch4.