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Shelf life and quality of banana cultivar Nendran as influenced by shrink–wrap packaging and storage temperature

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Abstract

Banana is the most widely cultivated fruit crop in Kerala. Nendran, a dual purpose cultivar is grown for consumption as vegetable in the unripe stage and also as fruit, upon ripening. An experiment was conducted during 2019-20 to extend the shelf life of this fruit through shrink wrapping, followed by storage under ambient and cool chamber conditions, after sanitizing with chlorine (100 ppm) followed by treatment with alum (1 %) and subsequently dipping in the fungicide, Carbendazim 50 WP (0.1 %). Initial titratable acidity and ascorbic acid contents of Nendran banana were 0.16 % and 6.06 mg 100g $^{-1}$ respectively. Total phenols and starch content of freshly harvested green Nendran banana were 145 mg 100g^{-1} and 84.0 % respectively. Shelf life of shrink wrapped fruits held in cool chamber could be extended to 45 days whereas the unwrapped fruits under ambient storage (control) became unmarketable after 7 days. The findings of the study revealed that physiological loss in weight and rate of respiration recorded an upward trend during storage while fruit firmness recorded a downward trend. Total soluble solids, titratable acidity and ascorbic acid rose with advancement of storage duration whereas total phenols and starch content declined. . The developed protocol could be used for long distance transportation to distant markets for internal trade as well as for shipment to foreign markets.

Keywords

Banana cv. Nendran, shrink wrapping, quality, shelf life

Introduction

Banana ranks first in terms of area and production, among fruit crops of Kerala, which is cultivated in an area of 57158 ha with a production of 489322 tonnes (1) and thus, placing it on records as one of the commercial fruit crops of the State. The cultivar, Nendran (genomic group, AAB) accounts for maximum area and production among the different cultivars grown in the State. Nendran is considered a dual purpose cultivar as it is cooked and consumed as vegetable in the raw form and upon ripening, consumed as fruit. Banana is fairly rich in carbohydrates, phenols, dietary fibre and also, rich in minerals like potassium and calcium. Nendran is the most sought after variety by the expatriates of Kerala origin and it is mainly exported to the Gulf countries, where a sizeable number of Keralites reside. Even though this cultivar is grown on a large scale in the State, many a time, huge production and the resultant market gluts are recurring phenomena. Post harvest losses of great magnitude are of regular occurrence in the markets of the State, as a result of which farmers do not get remunerative price for their produce. Besides, incidence of pathological rots is also responsible for losses encountered during post harvest handling. Several compounds are used to control post harvest diseases in fruits. Among them, Carbendazim which is popularly known by the trade names such as Bavistin, Benfil etc. and also, Mancozeb are invariably used in several countries. The standard maximum residue level (MRL) for Carbendazim currently established for China is 0.5 mg/kg, whereas in the European Union the MRL is 0.1mg/kg. As per the Food Safety and Standards Authority of India (FSSAI) rules, the MRL of Bavistin is 2 mg/kg. According to a study, the residue aspects of Carbendazim in mango, the prescribed acceptable daily intake (ADI) of Carbendazim is 0.03 mg kg body weight $^{-1}$ day^{-1} (2). Multiplying the ADI with the average body weight of an adult as 55 kg, the maximum permissible intake (MPI) would come to 1.65 mg person^{-1} day^{-1}. They concluded that since the theoretical maximum residue contribution (TMRC) was less than the MPI, application of Carbendazim and Mancozeb on mango at prescribed doses was safe from crop protection and consumer point of view. Maintenance of cool chain with appropriate infrastructure, pertaining to storage temperature and relative humidity is of paramount importance in retaining the quality of the fruit and also, for prolonging its shelf life. Packaging of any fresh produce is an essential post harvest operation which plays a vital role in maintaining freshness of the produce, which will ultimately determine the shelf life as well. The quality of banana for retail marketing depends on many aspects during post harvest handling which include storage, packaging, transportation etc. Adequate care taken at the time of harvest could reduce mechanical damage and would eventually protect the fruit from subsequent invasion by microbes (3). Low temperature handling and storage are the most important post handling methods to maintain quality and shelf life of banana (4). An atmosphere low in oxygen and high in carbon dioxide can influence the metabolism of the commodity being packed and the activity of decay causing microbes to enhance shelf life (5). In addition to the modification of atmosphere, packaging can also help retain the moisture content of the produce and can thus, reduce wilting or shriveling of the produce. Polymeric films have been widely used for packaging of fresh horticultural produce. Though they are non-biodegradable, polymeric films have a wide range of applications such as reduction in metabolic activities like respiration and transpiration, maintenance of texture and flavour properties and thus ultimately extending the marketability of the packaged produce. Therefore, the adoption of various post harvest handling techniques can significantly influence the shelf life as well as quality characteristics unique to a particular commodity. In this context, the present study focuses mainly on the effect of packaging and storage temperature on shelf life and quality of banana cv. Nendran, the most widely consumed cultivar in the Indian state of Kerala. Hence, the present investigation was carried out with the view of extending shelf life of banana cv.Nendran and also, to maintain its quality during post harvest handling.

Materials and Methods

Bunches of cv. Nendran, grown at the Banana Research Station, Kannara, Kerala Agricultural University, were harvested 85 days after bunch emergence (Fig. 6) (when the fingers lose their angularity and become round (fullness of fingers) and the bunches were quickly transported in plastic crates to the laboratory under the Department of Post-Harvest Technology, College of Agriculture . Dehanding (separation of hands from the bunches) was done immediately and the hands were kept on newspaper with the crown facing downward for 10 min, in order to facilitate drainage of exuding sap from the severed hands. This was followed by sorting, to remove the damaged, diseased and malformed fingers. The hands were then sanitized by treatment with 100 ppm chlorine, followed by dipping in 1 % alum solution for 3 min. The sanitized hands were then subjected to destaining (to remove remains of sap adhering on the peel which will ultimately hamper the marketability of fruits as sap injury appears as black patches when the fruit ripens) by gently rubbing the surface of the fruits with foam dipped in dilute detergent solution. The destained fruits were subsequently immersed in clean water to remove traces of detergent from the fruit surface. After destaining, the hands were treated with the fungicide, Benfil (Carbendazim 50 WP) by dipping in the solution @ 0.1 % for 5 min. The fruits treated with fungicide were then air dried under fan to remove excess moisture adhering on the surface of the fruits. The treated fruits were subsequently precooled in a cool chamber maintained at 12-13 ^{0}C, for 8 hrs. Finally, the fruits were subjected to shrink- wrapping of the hands using polyolefin film of 25 µ thickness (Fig. 7) and were held under two storage conditions viz. ambient temperature (32 -36 ^{0}C (maximum) and 18-22 ^{0}C (minimum) with 80-85 % RH) and at low temperature in a cool chamber (12-13 ^{0}C and 85-90 % RH) along with the unwrapped samples, which formed the control treatment. The entire experiment consisted of 4 treatments viz. T1- unwrapped samples (banana hands) stored under ambient conditions, T2- unwrapped samples (banana hands) stored in cool chamber, T3-shrink wrapped banana hands stored under ambient conditions and T4- shrink wrapped banana hands samples stored in cool chamber. The PLW values were determined by noting the cumulative % loss in weight from that of the initial fruit weight at the time of storage and the

Fig. 6. Mature green banana fruits of cv. Nendran.

Fig. 7. Shrink-wrapped banana fruits of cv. Nendran.

loss in weight noticed on the day of taking observation under both ambient and cool chamber conditions. Banana being a 'climacteric' fruit, the respiratory peak of various treatments and the loss in firmness were considered to arrive at the shelf of fruits and the values were expressed as number of days during which the fruits could retain the marketability. The fruits in a particular treatment was considered unmarketable after taking into consideration reduction in firmness and degree of ripeness. Respiratory rate of banana at the initial stage and during storage was determined with an oxygen/ carbon dioxide analyser (Model- DANSENSOR, Check Point O_2/CO_2, manufactured in Denmark). A digital display provided the amount of carbon dioxide liberated by the sample. The values were expressed in terms of % of CO_2 accumulated in the head space of the sample taken for recording the observation. Fruit firmness is an indicator of the degree of ripeness or the rate of biochemical reactions occurring in the fruits. Fruit firmness or the texture was determined with a digital tester (Vaiseshika, Model-6003E, manufactured in India) by inserting the plunger of the tester into the fruit after removing a slice of the fruit along with a portion of the rind. Fruit firmness values were expressed as force required in kg to penetrate of 1 cm of fruit pulp. Total soluble solids, which indicate the table quality of fruits were determined with a digital refractometer (ATAGO, PAL 1 & 2, manufactured in Japan) and the TSS content was expressed in % degree Brix (^{0} Brix). Measurement of titratable acidity is to determine the degree of ripeness of fruits. A known weight of the fruit sample was titrated against 0.1 N NaOH solution using phenolphthalein as an indicator. Malic acid being the predominant organic acid in banana, the acidity was expressed as % malic acid (6). Samples of banana fruit of known weight was titrated with 2, 6-dichlorophenol indophenol dye and the fruit extract was made up to the required volume using metaphosphoric acid as stabilizing agent (6). Estimation of total phenolics content was done using Folin-Ciocalteau reagent. The reaction of phenols with phosphomolybdic acid resulted in a blue coloured complex (Molybdenum blue) (7). The optical density values were recorded at 650 nm using a UV-Visible 1800 spectrophotometer (Shimadzu) manufactured in Japan. Determination of starch content in banana was done with anthrone reagent. The reaction of anthrone with per chloric acid resulted in a green coloured complex. The optical density values were recorded at 630 nm using a UV-visible spectrophotometer (8). The experiment was repeated twice using the Complete Randomized Design (CRD) and the data generated was statistically analyzed using the WASP (Web Agriculture Statistical Package). The cultivar Nendran is grown round the year in the State. Bunches were harvested from 2 successive crops to repeat the experiment. There were 4 replications in each treatment. Each replication consisted of 10 hands.

Results and Discussion

Shelf life and quality of banana cultivar Nendran were considerably influenced through shrink wrapping, followed by storage under optimum conditions. The effect of these techniques on shelf life and quality parameters are detailed below.

Physiological loss in weight (PLW)

Fruits, even after harvest are considered to be living organisms as they carry out their metabolic activities till they are consumed. Measurement of PLW gives an indication of the metabolic activity of fruits. PLW value reflect directly on the rates of metabolic activities like respiration and transpiration. A lower PLW value indicates slower metabolic activities in the fruit. PLW recorded an upward trend during storage in all the treatments (Fig. 1). Lowest PLW was observed in the shrink wrapped fruits stored in cool chamber, followed by the fruits shrink wrapped and kept under ambient conditions. Weight loss in unwrapped fruits under ambient conditions after 7 days of storage was 18.8 %, compared to the shrink wrapped fruits held in cool chamber which recorded only 13.8 % weight loss, after 42 days of storage. Lower PLW values in shrink wrapped fruits held at low temperature (cool chamber) may be due to the combined effects of slower biochemical reactions at low temperature and modification of atmosphere in shrink wrapped fruits, as a result of which the metabolic activities might have slowed down. This may have resulted in better retention of metabolites in the packaged fruits stored in cool chamber.

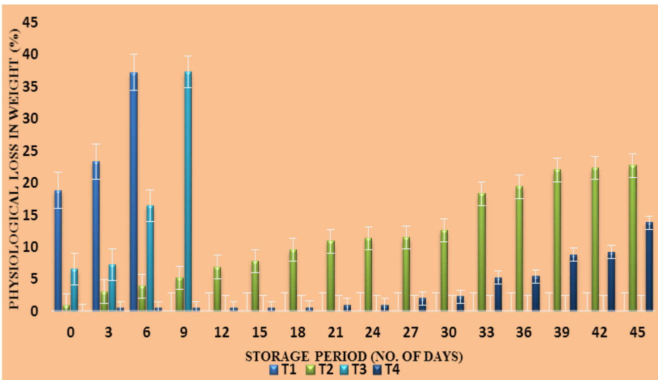

Fig. 1. Effect of shrink wrapping and storage temperature on physiological loss in weight (%) of banana cv.Nendran.

Further, shrink wrapping may have acted as a barrier against moisture loss through transpiration. The findings are in conformity with those reported in 'milk' banana (9) and in 'Dwarf Cavendish' banana (10). The highest value of weight loss (24.8 %) was recorded in unpackaged banana variety Williams I under ambient condition while the weight loss in variety Poyo packed in HDPE bags was just 2.1 % (11).

Respiration rate

Respiration is a catabolic process occurring in fruits either when attached to the plant or after detachment from the plant. Complex organic materials like polysaccharides, organic acids, protein etc. are degraded into simpler compounds during respiration. Measurement of respiratory activity would indicate the amount of substrate consumed or lost during respiration and it can be measured either by measuring the amount of oxygen consumed or carbon dioxide liberated. Rate of respiration showed an upward trend in all the samples, reached a peak and then showed a declining trend (Fig. 2). The rate was significantly lower in the shrink wrapped samples. The lowest rate of respiration was observed in the shrink wrapped fruits held at low temperature in cool chamber. Similarly, the days to reach the 'respiratory peak' also varied between treatments. For the unwrapped fruits under ambient conditions, it took 7 days to reach the 'respiratory peak' while it was 28 days for the unwrapped fruits in cool chamber and the shrink wrapped fruits under ambient conditions. The shrink wrapped fruits in cool chamber recorded the longest (35 days) duration to reach the 'respiratory peak'. Accumulation of CO_2 and depletion of O_2 in shrink wrapped samples may have reduced the respiratory activity of the fruits. Modified atmosphere packaging is proven to have beneficial effects on reducing weight loss and also in extension of shelf life of fruits. Moreover, low temperature storage may have further reduced the rate of respiration in the shrink wrapped fruits held in cool chamber. Modified atmosphere packaging along with low –temperature storage might have reduced the respiratory activity to a very significant level compared to the unpackaged samples held under ambient conditions. These observations are in consonance with those reported in modified atmosphere packaging of 'Robusta' banana (12) and in plantains (13).

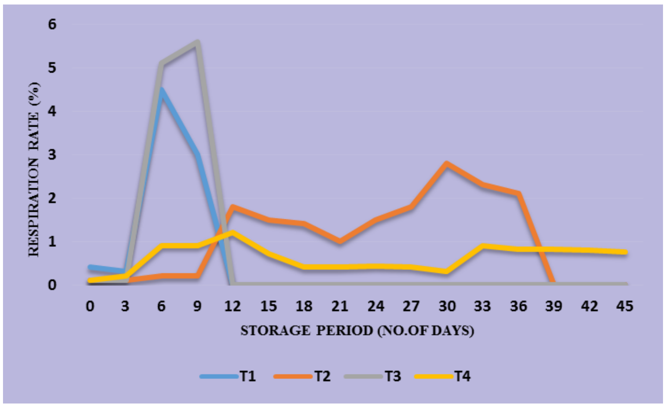

Fig. 2. Effect of shrink wrapping and storage temperature on respiration rate (%) of banana cv. Nendran.

T1- Unwrapped (ambient storage) T2- Unwrapped (cool chamber)
T3 – Shrink wrapped (ambient storage) T4–Shrink wrapped (cool chamber)

Shelf life

The marketable life of fruits are determined by several factors like stage of maturity, harvesting practices, post harvest handling techniques, pretreatments adopted etc. Packaging method and material as well as storage conditions including temperature, relative humidity and atmospheric gases surrounding the produce play vital role in extending or retarding the shelf life of fruits. Shrink wrapped banana stored in cool chamber had the highest shelf life of 42 days, followed by the fruits shrink wrapped and stored under ambient conditions (32 days). Unwrapped fruits stored in cool chamber had a shelf life of 28 days while the lowest shelf life (7 days) was recorded in the unwrapped fruits stored under ambient conditions (Fig. 3). Longer shelf life in shrink wrapped fruits may be due to the modification of atmosphere within the package leading to elevated levels of CO_2 and reduced levels of O_2. Atmosphere modification along with low temperature may have led to slower physiological and biochemical changes which resulted in the longest shelf life in shrink wrapped fruits stored in cool chamber. The findings are in agreement with a similar study (14) in mango variety 'Neelum'. Similar findings were also reported (10) in 'Dwarf Cavendish' and in 'Robusta' varieties of banana (12). A shelf life of 36 days in 3 banana cultivars of Ethiopia when packed in HDPE and LDPE bags, followed by ambient storage (10). However, in contrast to the findings in the present study, they reported a longer shelf life of 15 days for control (unpackaged) fruits.

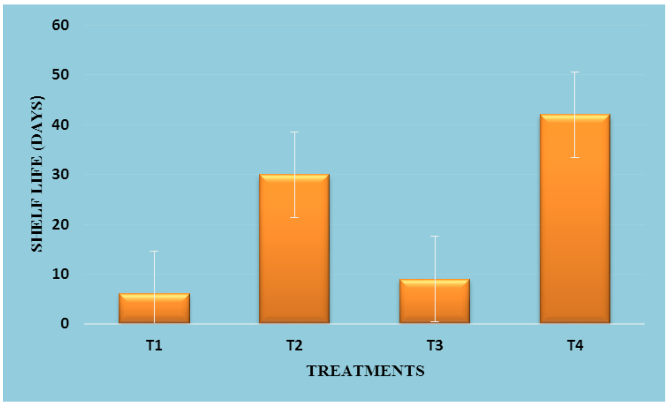

Fig. 3. Effect of shrink wrapping and storage temperature on shelf life (days) of banana cv.Nendran.

Fruit firmness

Texture of fruits is an indication of the degree of ripeness in fruits. During maturity and subsequent ripening process, the pectic polysaccharides in middle lamella of cell wall are degraded by enzymes like polygalacturonase and pectin methyl esterase resulting in the softness of tissues. The process gets accelerated at higher temperatures. Firmness of the fruit at the time of harvest was 0.52 $kgcm^{-2}$. Fruit firmness declined steadily in all the treatments during storage (Fig. 4). The decline was greatest in the unwrapped samples stored under ambient conditions. The decline was significantly lower in the shrink wrapped samples and also, the wrapped samples in cool chamber

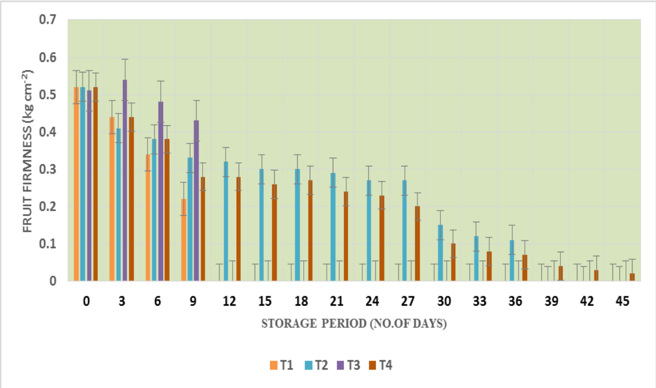

Fig. 4. Effect of shrink wrapping and storage temperature on fruit firmness (kg cm^{-2}) of banana cv.Nendran.

T1- Unwrapped (ambient storage) T2- Unwrapped (cool chamber)
T3 – Shrink wrapped (ambient storage) T4–Shrink wrapped (cool chamber)

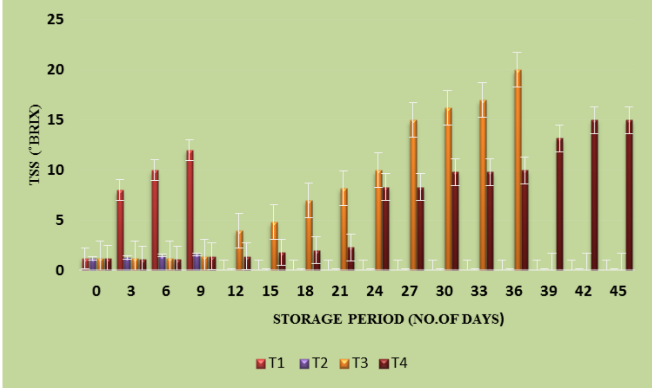

Fig. 5. Effect of shrink wrapping and storage temperature on TSS (^{0}Brix) of banana cv. Nendran.

T1- Unwrapped (ambient storage) T2- Unwrapped (cool chamber)
T3 – Shrink wrapped (ambient storage) T4–Shrink wrapped (cool chamber)

(low temperature) retained maximum firmness throughout storage. After 7 days of storage, the firmness was 0.28 $kgcm^{-2}$ in the unwrapped fruits under ambient conditions whereas, the wrapped fruits in cool chamber also had the same firmness, but after 42 days of storage. The loss in firmness could be due to the solubilisation of proto pectin into pectin. Higher retention of firmness in the wrapped samples may be due to lower rates of physiological and biochemical reactions as a result of modification of atmosphere in the packaged samples. This modification of atmosphere might have in turn reduced metabolic activities in the packaged fruits under ambient as well as in refrigerated storage. Similar trends were also reported (10) in 'Dwarf Cavendish' and in 'Robusta' varieties of banana (15). A steady decline in fruit firmness of three banana varieties of Ethiopia was reported (11) over a storage period of 36 days under ambient conditions and further, they also recorded faster reduction in firmness in the control (unpackaged) fruits compared to those packed in LDPE and HDPE bags.

Total soluble solids (TSS)

Total soluble solids have an important role on consumer acceptability of fruits as it is the most important quality attribute which determines the table quality of any fruit. It is also one of the important constituents of fruits contributing to the flavour. A higher TSS in fruits is usually preferred by consumers. TSS is constituted predominantly by sugars and to a lesser extent by organic acids, water soluble vitamins and minerals. Banana, owing to its high carbohydrate content usually has higher levels of TSS. In general, TSS content of fruits increases with advancement in maturity, with levels reaching the maximum in ripe fruits. An upward trend was recorded in TSS content of the fruits in all treatments during storage (Fig. 5). Rise in TSS was significantly higher in the unwrapped samples. Unwrapped samples under ambient conditions recorded a TSS content of 14 ^{0} Brix after 7 days of storage, whereas it was 18 ^{0} Brix in the wrapped samples held in cool chamber, after 42 days of storage. Increase in TSS of fruits during storage may be due to the hydrolysis of starch into sugars as result of the enzyme amylase which hydrolyses starch into disaccharides like sucrose. Further, sucrose is broken down into simple sugars like glucose and fructose by the enzyme invertase. These biochemical reactions result in increased sweetness in fruits during maturity and ripening. Higher levels of TSS in the unwrapped samples may be due to elevated levels of respiratory activity compared to the wrapped fruits. Higher levels of TSS in unwrapped fruits were also reported (12) in 'Robusta' variety of banana and in plantains (13).

Titratable acidity

Organic acids in fruits play an important role in determining the flavour of fruits along with total soluble solids. An ideal blend of TSS and organic acids contribute to the unique flavour which is identified with individual fruits and their varieties. Type of organic acid will vary with fruit and malic acid is the predominant organic acid in banana. All the samples under ambient and cool chamber storage recorded a rise in titratable acidity during storage (Table 1). The initial acidity was 0.16 %, which rose to 0.80 % after 7 days in the unwrapped fruits under ambient storage, whereas it was 0.64 % after 42 days in the shrink wrapped fruits in cool chamber. Higher levels of organic acid in unpackaged fruits under ambient conditions may be due to higher metabolic activities at higher storage temperatures in contrast to the samples stored under low-temperature conditions. An increase in titratable acidity of banana cv. Robusta during storage under ambient and in modified atmosphere conditions (12). However, these findings are in contrast to the reports of a previous study wherein a decline in titratable acidity of banana cv. Dwarf Cavendish with the advancement of storage period (10) was noticed. Acids could be considered as reserve sources of energy to the fruit and would, therefore, be expected to decline during the greater metabolic activity that occurs during ripening. There are exceptions, such as banana, where the highest level is attained at the fully ripe stage (16). However, another study (17) reported that titratable acidity increased up to two weeks after anthesis and thereafter, it decreased. After eight weeks into anthesis, it declined to 1.58 mg $100g^{-1}$.

Ascorbic acid

Being a potent antioxidant compound, ascorbic acid, also known as vitamin C is a vital nutrient which plays a key role in human health. It is known for the immunity boosting properties. Fresh fruits, vegetables and their

Table 1. Effect of shrink wrapping and storage temperature on titratable acidity (%) and ascorbic acid content (mg 100 $^{-1}$ g) of bananacv.Nendran

Treatments	Initial		1st week		2nd week		3rd week		4th week		5th week		6th week	
	Acidity	Ascorbic	Acidity	Ascorbic acid	Acidity	Ascorbic	Acidity	Ascorbic	Acidity	Ascorbic	Acidity	Ascorbic	Acidity	Ascorbic
T1	0.16	6.06	0.80*	10.40*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T2	0.16	6.06	0.32	10.02	0.36	12.40	0.47	13.02	0.68*	14.00*	0.00	0.00	0.00	0.00
T3	0.16	6.06	0.30	11.60	0.34	12.80	0.40	13.40	0.50	14.60	0.54*	15.04*	0.00	0.00
T4	0.16	6.06	0.16	8.80	0.16	9.04	0.16	9.06	0.22	11.14	0.42	12.60	0.64	14.06
CD (at 5%)	NS		0.097	0.249	0.013	0.133	0.032	0.095	0.027	0.021	0.023	0.026	0.036	0.028
SE(±m)	NS		0.044	0.114	0.005	0.061	0.015	0.044	0.012	0.010	0.01	0.012	0.0	0.013
SE (± d)	NS		0.176	0.456	0.02	0.244	0.06	0.176	0.048	0.04	0.044	0.048	0.068	0.052

NS-Non significant;* Unmarketable;T1- Unwrapped (ambient storage);T2- Unwrapped (cool chamber);T3 – Shrink wrapped (ambient storage); T4 – Shrink wrapped (cool chamber)

processed products are the limited sources of this vital nutrient as our body cannot synthesize vitamin C. Though banana is not a rich source of vitamin C, it is one of the cheapest sources as the fruit is predominantly grown in developing and under developed nations. The initial ascorbic acid content of mature green fruits was 6.06 mg100g^{-1}. Ascorbic acid levels showed an upward trend with the advancement of storage period (Table 1). The unwrapped samples under ambient conditions had 10.4 mg 100 g^{-1}, after 7 days of storage, whereas the shrink wrapped fruits in cool chamber recorded the lowest content throughout the storage period. Lower levels of ascorbic acid in packaged fruits might be due to slower rates of metabolic activities in these samples. Further, shrink –wrapped fruit held in cool chamber had the lowest ascorbic acid content throughout storage as a result of significantly lower rates of biochemical reactions in the packaged fruits. These reactions might have been further slowed down when the fruits were held in cool chamber. Rise in ascorbic acid content during storage may be due to the increase in lipid peroxidation, which is coincident with ripening. Similar findings were also reported in 'Hom Thong' and 'Khai' bananas (18) and also in 'Dwarf Cavendish' banana (10).

Total phenols

Phenolic compounds are potent antioxidant compounds having direct health promoting properties. In general, immature fruits have higher phenolic compounds which are degraded during maturity and ripening as a result of the action of enzyme polyphenol oxidase. Though higher levels of phenolic compounds in fruits are important from the health point of view, they are also known to impart an astringent or tart flavour to fruits, which is disliked by some consumers. Mature green banana had an initial phenol content of 145 mg 100g^{-1}. Total phenols in all the samples showed a declining trend (Table 2.). The unwrapped fruits under ambient conditions recorded the highest decline (34%), after 7 days, whereas the wrapped fruits held in cool chamber retained 24 % of total phenols, after 42 days of storage. Reduction in total phenolics of banana might be due to oxidation of polyphenols aided by the enzyme, polyphenol oxidase in the presence of atmospheric oxygen. Declining trend in total phenols was also reported in banana and mango during storage (19). Fall in phenolic compounds during storage and ripening was reported in 'Hom Thong' banana (18). With advancement in maturity, phenolics are polymerized to

Table 2. Effect of shrink wrapping and storage temperature on total phenols (mg 100 $^{-1}$ g) and starch content (%) of banana cv.Nendran

Treatments	Initial		1st week		2nd week		3rd week		4th week		5th week		6th week	
	Total Phenols	Starch	Total Phenols	Starch	Total Phenols	Starch	Total Phenols	Starch	Total Phenols	Starch	Total Phenols	Starch	Total Phenols	Starch
T1	145.00	84.00	50.00*	18.45*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T2	145.00	84.00	50.00	53.20	36.00	40.06	35.00	38.20	25.00*	36.80*	0.00	0.00	0.00	0.00
T3	145.00	84.00	60.00	80.00	42.00	74.00	38.00	68.00	31.00	54.80	26.00*	38.40*	0.00	0.00
T4	145.00	84.00	110.00	82.00	65.00	76.00	55.00	70.00	48.00	64.50	42.00	52.60	35.00	40.06
CD(at 5%)	NS		1.883	0.163	0.326	0.133	0.331	0.095	0.331	0.133	1.271	0.221	1.258	0.239
SE(±m)	NS		0.864	0.075	0.150	0.061	0.152	0.044	0.152	0.061	0.583	0.101	0.577	0.110
SE (± d)	NS		3.456	0.3	0.6	0.244	0.608	0.176	0.608	0.244	2.332	0.404	2.308	0.440

NS-Non significant;* Unmarketable ;T1- Unwrapped (ambient storage);T2- Unwrapped (cool chamber);T3 – Shrink wrapped (ambient storage); T4–Shrink wrapped (cool chamber) insoluble compounds, resulting in a reduction in astringency in the ripe banana fruit. Higher levels of phenolic compounds in the wrapped samples may be due to lower rates of biochemical reactions as a result of atmosphere modification through shrink wrapping. Moreover, storage of shrink-wrapped samples in cool chamber may have further reduced the rates of biochemical reactions. Similar trends were reported in 'Mas' banana stored in polybags (20).

Starch content

Starch is a polysaccharide found in fruits particularly at the immature stage. Higher levels of starch are found in unripe fruits as compared to their ripe counterparts. As fruits mature and with advancement in maturity and ripening, starch is hydrolyzed by the enzyme amylase into the disaccharide, sucrose. Sucrose is further degraded to monosaccharides glucose and fructose by the enzyme invertase which results in increased sweetness in fruits at the onset of ripening. Initial starch content in mature green banana was 84.00 %. A steady decline in starch content was observed in all the treatments during storage. However, the wrapped samples retained higher levels of starch throughout the storage period (Table 2). Higher levels of starch in shrink-wrapped samples may be due to slower rates of starch hydrolysis as a result of atmospheric modification. The unwrapped fruits under ambient conditions retained only 18.45 % starch after 7 days of storage whereas the wrapped samples in cool chamber had 40.06 %, after 42 days. Elevated levels of CO_2 in the shrink wrapped fruits may have retarded the rate of conversion of starch into sugars. Higher levels of starch were reported in modified atmosphere banana (21) and also in plantains (13). Further, low-temperature storage in combination with packaging might have reduced the biochemical activities of samples held under these conditions to a considerable level.

Conclusion

Based on the findings of the study, it can be concluded that shrink wrapping of banana cv. Nendran with polyolefin film of 25 µ thickness, after necessary sanitization and fungicidal treatments, followed by precooling and subsequent storage can prolong the shelf life considerably. Further, holding the wrapped fruits in a cool chamber maintained at 12-13 ^{0} C and 85-90 % relative humidity can significantly extend the shelf compared to the unwrapped samples stored under ambient conditions. Shelf life of banana cultivar Nendran could be extended to 42 days following the protocol adopted in the present study. Shrink wrapping in combination with low temperature storage is an ideal post harvest handling technique to prolong shelf life and also to maintain quality of the fruits during storage. The findings of the present study reveals that the protocol adopted for post harvest handling of banana cultivar Nendran is ideal for long-distance transportation.

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Authors contributions

The research was conducted as part of the Project Grant shown above. SG conceived the research, wrote and edited the manuscript. AAP and SK assisted in analytical work and compilation of data. MJ did the overall supervision.

Compliance with ethical standards

Conflict of interest: No conflict of interest exists among authors.

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