Individual shrink wrapping extends the storage life and maintains the antioxidants of mango (cvs. ‘Alphonso’ and ‘Banganapalli’) stored at 8 °C

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Abstract Freshly-harvested mature green mangoes (cvs. ‘Alphonso’ and ‘Banganapalli’) were individually shrink wrapped using two semi-permeable Cryovac films® (D-955 and LD-935) and a locally available LDPE film. The shrink wrapped and non-wrapped fruit were stored at 8 °C for 5 weeks and transferred to ambient conditions for subsequent ripening, to study the feasibility of alleviation of chilling injury (CI) and to determine shrink wrapping effect on fruit quality. Shrink wrapped mangoes of ‘Banganapalli’ and ‘Alphonso’ cultivars packed in D-955 (15 µm thickness) film could be stored for 5 weeks at 8 °C in fresh and unripe green condition. After storage, these cultivars respectively lost only 0.5 and 1.4 % mass in case of shrink wrapping as compared to 5.8 and 6.9 % loss in non-wrapped fruit. After removal from low temperature and unwrapping, shrink wrapped mangoes showed normal respiratory behaviour with production of CO₂ and ethylene peaks (climacteric peaks) during ripening, whereas non-wrapped fruit did not show any respiratory peaks. Shrink wrapped mangoes ripened normally within a week at ambient temperature (24–32 °C and 60–70 % RH) with good surface yellow colour (reflected by hue and chroma values), edible softness, retention of nutritional quality and acceptable organoleptic quality. These quality parameters were better in fruit wrapped with D-955 film compared to

LD-935 and LDPE films. Total carotenoids in terms of β-carotene content were significantly higher in shrink wrapped fruit when compared to non-wrapped fruit. Among different shrink films, total antioxidant capacity and DPPH radical scavenging abilities were higher in LD-935 wrapped fruit in case of ‘Alphonso’ cultivar whereas these were on par in LD-935 and D-955 film wrapped fruit in case of ‘Banganapalli’ cultivar.

Keywords Mango · Shrink wrapping · Storage life · Respiration · Ripening quality · Antioxidants

Introduction

Individual shrink wrapping, which may be considered as modified atmosphere packaging (MAP) for individual fruit, is used to enhance the storage life and maintain freshness of fruits and vegetables. This technique has been successfully used for non-climacteric fruits and vegetables like citrus, pomegranate, cucumber, capsicum, etc. mainly to prevent shrivelling and mass loss, without affecting the flavour (Ben-Yehoshua et al. 1983a; Sonkar and Ladaniya 1999; Sudhakar Rao et al. 2000; Nanda et al. 2001; Dhall et al. 2012). Maintenance of freshness, in non-climacteric produce by shrink wrapping, is mainly due to reduction of water stress rather than atmospheric modification around the produce (Ben-Yehoshua et al. 1983a, b). However, Zong (1991) attributed delayed senescence of cucumbers and Chinese cabbages due to combined effect of increased humidity and altered atmosphere composition by individual film wrapping. Individual shrink wrapping was also reported to extend the storage life of some climacteric commodities such as apple (Sharma et al. 2013), peaches (Singh et al. 2009), persimmon (Kawada 1982), guava (Pal et al. 2004) and papaya (Singh and Sudhakar Rao 2005a). However, attempts to delay ripening

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and extend the storage life of other climacteric fruits like mango, melons, tomato, etc. either at ambient temperature or at optimum low temperature were not fully successful. Shrink wrapping enhanced undesirable flavour changes and significantly affected the taste of muskmelon during storage (Collins et al. 1990). In mangoes or tomatoes, shrink wrapping with non-perforated films caused impaired ripening and off-flavour development (Miller et al. 1983, 1986; Floros et al. 1987). Attempts made earlier on shrink wrapping of four mango cultivars ('Alphonso', 'Banganapalli', 'Langra' and 'Dashehari') using different heat shrinkable films though delayed ripening at both 25 and 15 °C, but failed to ripe normally even after removing the films (Shantha and Sudhakar Rao 1997). The capability of shrink film wrapping to retard the physiological changes in fruit tissue depends upon the extent of atmospheric modification in or around the fruit. The negative effects are apparently related to the composition of the modified atmosphere generated inside the shrunk packages at higher temperatures, which is inappropriate for these fruit. As mango has high respiration rate, the permeability of presently available heat-shrink films could not match its respiration rate at higher storage temperature of 13 °C, which is optimum for its storage. Hence, in the present study, attempts were made to see the feasibility of storing shrink wrapped mangoes at sub optimal temperature of 8 °C, so as to bring down the respiration rate of mangoes to match the film permeability and also to take the advantage of atmospheric modification for alleviation of chilling injury, in further extending its storage life.

Materials and methods

'Alphonso' and 'Banganapalli' mangoes were harvested (during last week of May 2010) at physiological maturity stage from the experimental orchard of the Indian Institute of Horticultural Research, Hessaraghatta, Bangalore, wherein the recommended pre-harvest disease management practices were followed. Fruit free from mechanical damage, blemishes or diseases were randomly selected to maintain homogeneity in the experiment and washed in running tap water to remove adhering sap or dirt. Fruit were then dipped in fungicide solution (500 ppm Prochloraz 45 EC™) for 10 min, drained and surface dried before being shrink wrapped or used as control.

Individual shrink wrapping Mangoes were shrink wrapped individually using three semi permeable films having different gas permeabilities : (i) D-955 (a multi layered electronically cross-linked polyolefin film of 15 µm), (ii) LD-935 (a multi layered co-extruded polyolefin film of 11 µm)-both procured from Cryovac, W. R. Grace and Co., Duncan, S.C. and (iii) 25 µm thick locally available LDPE film. The oxygen transmission rates (ml/m².day) of these films respectively were

8,548, 10,200, 7,800; carbon dioxide transmission rates (ml/m².day) were 27,353, 50,100, 42,000 and water vapour transmission rates (WVTR, g/m².day) were 21.4, 24.8, 23.0. These films were selected based on the preliminary results of previous trials.

Fruit were individually sealed in the above films using an L-bar sealer (Weldotron model 6300- L) and then heat-shrunk by passing them through a heat-shrink tunnel (Weldotron model 7121A, Weldotron Corporation, New Jersey) for 10–15 s at 300–350 °F (150–175 °C). The shrink wrapped and non-wrapped mangoes were master packed in CFB boxes (5 replications per treatment and each replication consists of 16 fruit) and stored at 8 °C in a walk-in-cold room. After 5 weeks at 8 °C, the shrink wrapped fruit (after unwrapping) were shifted to ambient temperature (24–32 °C and 60–70 % RH) for ripening.

Respiration and ethylene production rates To study the effect of shrink wrapping on the physiological response of fruit stored at 8 °C, respiration (ml CO₂/kg/h) and ethylene production (µl/kg/h) rates in mangoes were measured during ripening under ambient conditions (24–32 °C and 60–70 % RH). These measurements were carried out after unpacking the fruit, which were shifted from 8 °C storage after 5 weeks. Six replicates of a single fruit (weighing 275±25 g in 'Alphonso', 375±25 g in 'Banganapalli') were enclosed in air-tight respiratory jars (1.3 L) for ≤1 h, after which a sample of headspace gas was drawn and injected into the gas chromatograph (Agilent 6890 Series) fitted with a Porapak Q column. CO₂ was detected using a thermal conductivity detector (TCD) with N₂ as the carrier gas (30 ml/min). Ethylene was measured using another (HP 5890 Series II) gas chromatograph fitted with a Porapak Q column equipped with a flame ionisation detector (FID), under similar conditions. Injector, oven and detector temperatures were set at 100, 100 and 110 °C respectively during above measurements (Sudhakar Rao and Gopalakrishna Rao 2008).

Physiological loss in weight (PLW) and fruit firmness Weights of 15 individual fruit from each treatment were recorded after 5 weeks at 8 °C, and also after ripening under ambient conditions. Cumulative losses in mass were calculated as percentages of the initial mass. Fruit firmness was measured at two equatorial positions on each fruit, using an Instron-4201 Universal testing machine (Instron Corporation, Canton, MA, USA). This was fitted with an 8 mm diameter cylindrical plunger and a 500 kg load cell moving at a cross-head speed of 100 mm/min.

Fruit surface and pulp colour The surface colour of fruit was measured by using a colorimeter, Color Reader, CR-10 (Minolta Co., Ltd, Osaka, Japan; measuring area of 8 mm with 8/d viewing geometry using CIE Standard illuminant

D65) and expressed in terms of L (lightness), C (chroma) and H (hue) values. L represents lightness of the color and ranges from 0 (black) to 100 (white). Hue is the actual colour of an object such as red, green, orange, yellow, blue, etc. On a colour wheel subtending 360°, red-purple are placed at the far right (or an angle of 0°); yellow, bluish-green and blue follow at 90° 180° and 270°, respectively. Chroma represents the purity/saturation of a colour, how pure or intense the hue is. The fruit surface colour was measured by taking readings at three different positions on the fruit surface. Similarly, pulp colour was examined by taking the homogenized mango pulp into a transparent glass cup.

Quality attributes Five fruit per replication were selected at random from each treatment and analysed, to study biochemical changes after storage and ripening. Small pieces of pulp were cut and immediately stored at -21 °C until chemical analysis. The samples were thawed and homogenised using virTishear (Virtis Company Inc., Gardiner, NY, USA), before estimating total soluble solids (TSS) as °Brix, sugars (total and reducing), ascorbic acid (mg/100 g), titratable acidity (TA %) and total carotenoids (µg/100 g) using standard methods of analysis (AOAC 1995). TSS was measured using a hand refractometer (Erma Inc., Tokyo, Japan) and values were corrected to 20 °C. Carotenoids were extracted with acetone until the pulp became colourless and pigments were then transferred into the petroleum ether phase. The absorbance was measured at 452 nm using a Spectronic 1201 spectrophotometer (Milton Roy Co., NY, USA). The total phenols, flavonoids, antioxidant capacity (FRAP) and DPPH radical scavenging abilities were estimated using the methods as described by Shivashankara et al. (2010). Total phenols were expressed as mg of gallic acid equivalents, flavonoids as mg of catechin equivalents, FRAP and DPPH as mg of ascorbic acid equivalent antioxidant capacity (AEAC) per 100 g fresh weight.

Sensory evaluation Sensory evaluation of mangoes after ripening was carried out by a panel of ten judges for general appearance, pulp colour, texture, flavour and overall acceptability using a 5-point Hedonic scale (1=very bad, 2=poor, 3=fair, 4=good, 5=very good) for each attribute.

Statistical analysis The experiment was laid out in completely randomized design. Data were analyzed by ANOVA and significance among treatment mean values was determined by Duncan's multiple comparison test at the $p < 0.05$ level.

Results and discussion

Respiration and ethylene production The respiration rates of unpacked mangoes measured during ripening under ambient

conditions, after 5 weeks at 8 °C, indicated that 'Alphonso' had a higher respiration rate than 'Banganapalli', irrespective of the packaging treatment (Fig. 1). Sudhakar Rao and Gopalakrishna Rao (2009) also reported higher respiration rate of 'Alphonso' than 'Banganapalli' cultivars during ripening under ambient conditions after 6 weeks at 8 °C, irrespective of the Controlled Atmosphere storage treatment. The respiration rate of non-wrapped fruit in both cultivars increased continuously during ripening under ambient conditions, after 5 weeks at 8 °C. However, shrink wrapped 'Alphonso' mangoes, irrespective of the film, showed a typical pattern of climacteric rise during ripening under ambient conditions. 'Alphonso' mangoes wrapped with D-955 and LDPE film showed climacteric peaks (155.4 and 149.8 ml CO₂/kg/h respectively) after 2 days of shifting to ambient conditions, whereas those wrapped with LD-935 film showed a lesser climacteric peak (129.4 ml CO₂/kg/h) after 3 days of shifting (Fig. 1). Similarly, 'Banganapalli' mangoes shrink wrapped with all the three films showed climacteric peaks after 2 days of shifting to ambient conditions. The continuous increase in respiration rate of non-wrapped mangoes could be associated with the expression of chilling injury during ripening. Whereas the normal climacteric respiration behaviour in shrink wrapped mangoes indicates the alleviation of this low temperature stress by wrapping the fruit with low permeability films. The alleviation of chilling injury in mangoes by individual shrink wrapping may be due to maintaining high RH around the produce (Ben-Yehoshua et al. 1981), in addition to favourable atmospheric modification in or around the produce during 5 weeks at 8 °C.

Shrink wrapped fruit of both cultivars showed ethylene peaks during ripening, contrary to non-wrapped mangoes which showed a continuous increase in ethylene production after shifting to ambient conditions (Fig. 2). Ethylene peaks were observed one day after appearance of respiratory climacteric in case of 'Alphonso' mangoes shrink wrapped with LDPE and D-955 films (1.51 and 1.06 µl/kg/h respectively), whereas those wrapped with LD-935 film showed a lesser ethylene peak (0.87 µl/kg/h) coinciding with the respiratory climacteric (Figs. 1 and 2). In case of 'Banganapalli' cultivar, fruit shrink wrapped with all the three films showed ethylene peaks coinciding with the respiratory climacteric. This indicates that the shrink wrapped mangoes had the capacity to ripe properly with normal ethylene production behaviour at ambient conditions, even after 5 weeks at chilling temperature of 8 °C.

Physiological loss in weight (%) Shrink wrapping of mangoes significantly reduced mass loss during 5 weeks at 8 °C, irrespective of cultivar or film used for wrapping (Table 1). The mass loss in shrink wrapped fruit was 4 to 5 times less in 'Alphonso' cultivar and 9 to 10 times less in 'Banganapalli' cultivar compared to non-wrapped fruit, depending on the film

Fig. 1 Respiration rates of shrink wrapped mangoes during ripening under ambient conditions (24–32 °C, 60–70%RH), after storage at 8 °C for 5 weeks. Error bars represent $\pm$ SE. Each value is the mean for six replicates

used. Shrink wrapping effectively reduced the transpiration rate of mangoes due to the low WVTR of the films, thereby significantly reducing the mass loss. The low permeability of the shrink films to oxygen and carbon dioxide might have further contributed to the reduction of respiration rate and ripening related physiological changes leading to less mass loss. Reduction in mass loss by shrink wrapping has also been reported by Nanda et al. (2001) in pomegranate, Ladaniya et al. (1997) in 'Nagpur' mandarins and Miller et al. (1983) in mango, Hale et al. (1986) in Florida grapefruit, Singh and Sudhakar Rao (2005a) in papaya, Sudhakar Rao et al. (2000)

and Dhall et al. (2012) in cucumber. Following storage, after unpacking and shifting to ambient temperature for ripening, the mass loss of shrink wrapped fruit increased significantly in both cultivars of mango. This is mainly attributed to the losses due to normal physiological changes including ripening. Even then, the cumulative mass loss (storage and ripening) in both cultivars was significantly lower in shrink-wrapped fruit than non-wrapped fruit (Table 2). Among different films, the cumulative mass loss was significantly low in LDPE wrapped fruits in both cultivars.

Fig. 2 Ethylene production rates of shrink wrapped mangoes during ripening under ambient conditions (24–32 °C, 60–70 % RH), after storage at 8 °C for 5 weeks. Error bars represent $\pm$ SE. Each value is the mean for six replicates

Table 1 Effect of shrink wrapping on the physico-chemical changes in mango stored at 8 °C for 5 weeks

Cultivar/Shrink Film	PLW, %	Fruit surface colour		Firmness, kg/cm ²	TSS, Brix	TA, %	Reducing sugars, %	Total sugars, %	Carotenoids, µg/100 g	Pulp colour	
		L	Hue							Hue	Chroma
‘Alphonso’											
At Harvest	0	51.53±1.29	115.58±1.34	37.44±0.98	45.35±1.09	8.12±0.24	3.08±0.16	1.35±0.11	300±28	89.19±0.41	41.89±0.48
D-955 film	1.41 ^d	52.23 ^b	115.25 ^a	29.85 ^e	26.41 ^c	16.33 ^c	2.09 ^{bc}	3.35 ^d	1671.33 ^a	87.71 ^d	45.90 ^a
LD-935 film	1.74 ^c	54.27 ^a	112.76 ^c	32.57 ^c	18.72 ^f	17.77 ^a	1.97 ^c	3.40 ^d	1658.50 ^a	87.61 ^d	45.64 ^a
LDPE film	1.42 ^b	50.10 ^c	113.80 ^b	30.89 ^d	15.52 ^g	16.80 ^b	2.11 ^b	3.01 ^e	1326.80 ^b	87.01 ^e	43.71 ^b
Non-wrapped	6.87 ^a	46.10 ^e	110.05 ^d	38.89 ^a	31.29 ^a	17.60 ^a	2.42 ^a	3.06 ^e	1363.13 ^b	87.07 ^e	42.53 ^c
‘Banganapalli’											
At Harvest	0	53.29±0.78	112.8±1.02	35.8±1.15	34.19±0.96	8.02±0.20	1.3±0.11	3.12±0.19	230±22.0	95.59±0.50	33.57±0.22
D-955 film	0.53 ^f	51.77 ^b	112.57 ^c	29.35 ^e	25.17 ^d	16.60 ^{bc}	0.81 ^e	4.79 ^b	1048.90 ^c	88.47 ^c	37.48 ^d
LD-935 film	0.68 ^e	52.10 ^b	108.64 ^c	31.80 ^{cd}	20.61 ^e	16.60 ^{bc}	0.83 ^e	5.15 ^a	733.40 ^d	89.72 ^b	34.17 ^e
LDPE film	0.69 ^e	49.80 ^c	110.54 ^d	28.4 ^f	15.04 ^g	16.70 ^b	1.10 ^d	4.20 ^c	745.70 ^d	87.80 ^d	34.76 ^e
Non-wrapped	5.75 ^b	47.63 ^d	106.06 ^f	34.58 ^b	29.21 ^b	15.80 ^d	1.22 ^d	4.78 ^b	614.04 ^e	91.58 ^a	30.18 ^f
LSD (P<0.05)	0.08	2.46	1.71	1.88	2.02	0.73	0.20	0.54	94.33	1.26	2.50

Means within the same column and section with different superscripts are significantly different ($p<0.05$). Each value is the mean for five replicates

Surface colour The Hunter ‘L’ value of shrink wrapped (especially LD-935 and D-955 film) mangoes, that indicates brightness of the fruit, was significantly higher than non-wrapped mangoes in both cultivars after 5 weeks at 8 °C (Table 1). Among different films, fruit wrapped with LDPE film had significantly lower Hunter ‘L’ value, but still significantly higher than non-wrapped fruit in both cultivars. Irrespective of the variety and treatment, all mangoes were green in colour as indicated by hue angle (>110), even after 5 weeks. The intensity of green colour (chroma) was slightly more in case of non-wrapped than shrink wrapped fruit. After ripening also, non-wrapped mangoes of both cultivars had significantly lower Hunter ‘L’ values when compared to shrink wrapped fruit (Table 2). Among different films, fruit wrapped with LDPE film had significantly lower Hunter ‘L’ value as before ripening, in both cultivars. Shrink wrapped fruit of both cultivars had lower hue angle (<75) after ripening, indicating yellowish red surface colour with more intensity (high chroma values) than non-wrapped fruit. In case of ‘Alphonso’ cultivar, fruit shrink wrapped with D-955 film (that developed dark orange yellow surface colour) had significantly lower hue angle (70.97) and higher chroma value (61.53) compared to other films (Table 2).

Firmness The firmness measured at harvest was 34.19 and 45.35 kg/cm² in case of ‘Banganapalli’ and ‘Alphonso’ cultivars, respectively (Table 1). After 5 weeks at 8 °C, the decrease in firmness was lower in non-wrapped fruit as compared to shrink wrapped fruit in both cultivars. This indicates the ripening process during storage at 8 °C was affected in non-wrapped fruit due to chilling injury. Shrink wrapped fruit could overcome this low temperature stress and exhibited slow but steady ripening changes. Among different films, fruit of both cultivars wrapped with D-955 film had significantly higher firmness and those wrapped with LDPE film had the least firmness. The difference observed in firmness values of fruit wrapped with different films (Table 1) is due to their varying permeability to respiratory gases. Once the fruit were shifted to ambient temperature after unwrapping, the fruit firmness decreased drastically in both cultivars irrespective of the treatment. Shrink wrapped fruit of both cultivars reached ripe stage with edible softness (3.0 to 4.5 kg/cm²) after one week of shifting to ambient temperature (Table 2). Whereas, non-wrapped fruit did not attain edible softness and were little harder (8.0 to 10.5 kg/cm²) indicating hindrance of ripening due to CI. This was also reflected by lower scores for pulp texture (Table 4) during organoleptic evaluation in case of non-wrapped fruit compared to shrink wrapped fruit with different films. The non-wrapped fruit of both cultivars failed to ripen properly with CI symptoms of uneven ripening, thereby did not reach edible softness. Lederman et al. (1997) also observed that ‘Keitt’ mangoes stored at 0, 2 and 5 °C for 4 weeks stayed quite firm and did not soften normally upon

Table 2 Effect of shrink wrapping on the physico-chemical changes in mango stored for 5 weeks at 8 °C followed by 1 week ripening at ambient conditions (24–32 °C and 60–70 % RH)

Cultivar/Shrink Film	PLW, %	Surface colour			Firmness, kg/cm ²	TSS, Brix	TA, %	Vit. C, mg %	Reducing sugars, %	Total sugars, %	Carotenoids, µg/100 g	Pulp colour	
		L	Hue	Chroma								Hue	Chroma
‘Alphonso’													
D-955 film	9.03 ^c	67.10 ^b	70.97 ^f	61.53 ^a	3.87 ^d	19.77 ^a	0.36 ^d	60.93 ^a	5.16 ^c	14.09 ^b	9532.27 ^b	75.38 ^c	53.22 ^b
LD-935 film	9.14 ^c	64.70 ^d	75.07 ^c	57.06 ^b	3.72 ^e	18.53 ^b	0.38 ^d	52.89 ^b	4.74 ^e	14.17 ^b	9946.67 ^a	76.51 ^c	57.18 ^a
LDPE film	7.75 ^f	59.73 ^e	73.13 ^e	56.85 ^b	2.95 ^f	16.73 ^c	0.38 ^d	53.14 ^b	4.60 ^f	13.10 ^c	7900.00 ^c	76.06 ^d	48.43 ^c
Non-wrapped	15.57 ^a	55.20 ^f	78.97 ^b	47.58 ^c	8.05 ^b	17.20 ^d	0.65 ^a	27.67 ^c	3.84 ^g	12.44 ^d	4892.00 ^d	76.66 ^c	43.78 ^d
‘Banganapalli’													
D-955 film	8.27 ^d	66.97 ^b	72.71 ^e	53.73 ^d	4.44 ^c	18.00 ^c	0.34 ^{de}	15.75 ^d	5.03 ^d	14.87 ^a	3620.00 ^f	81.28 ^b	38.68 ^f
LD-935 film	7.89 ^{ef}	68.50 ^a	73.82 ^d	53.00 ^d	4.53 ^c	17.30 ^d	0.32 ^e	12.14 ^c	5.63 ^a	14.11 ^b	3935.00 ^e	81.22 ^b	39.77 ^e
LDPE film	8.01 ^e	66.20 ^c	73.75 ^d	55.52 ^c	3.09 ^f	16.87 ^f	0.58 ^b	12.75 ^c	5.33 ^b	12.31 ^d	3655.30 ^f	81.66 ^b	38.84 ^f
Non-wrapped	15.08 ^b	60.07 ^e	84.17 ^a	42.69 ^f	10.49 ^a	16.13 ^c	0.54 ^c	7.56 ^f	5.06 ^d	12.09 ^e	1128.83 ^g	81.53 ^b	33.26 ^g
LSD (<i>P</i> <0.05)	0.57	1.61	1.2	2.31	0.44	0.95	0.05	3.75	0.23	0.59	262.82	0.91	2.53

Means within the same column and section with different superscripts are significantly different ($p < 0.05$). Each value is the mean for five replicates

transfer to 20 °C for ripening. Shrink wrapping might have resulted in favourable atmospheric modification in or around the produce that helped in alleviation of CI during 5 weeks at 8 °C and normal ripening of fruit after shifting to ambient temperature.

Changes in quality attributes Although fruit were green in colour after 5 weeks at 8 °C, the TSS, sugars and carotenoids content increased and TA decreased in both cultivars irrespective of the treatment. The changes in these parameters were more in shrink wrapped mangoes than non-wrapped fruit, indicating steady progress of ripening in the former. The TA of mangoes at harvest was 3.0 % and 1.3 % in ‘Alphonso’ and ‘Banganapalli’, respectively. It declined to about 2.0 and 0.8 % in shrink wrapped fruit when compared to 2.42 and 1.22 % in non-wrapped fruit of these cultivars respectively (Table 1). Among films, the TA content was higher in fruit wrapped with LDPE film. Similarly, the total carotenoid content of ‘Alphonso’ and ‘Banganapalli’ cultivars at harvest were 300 and 230 µg/100 g respectively and increased to 1,671 and 1,049 µg/100 g respectively in shrink wrapped (D-955 film) fruit. Among different films, fruit wrapped with LDPE film had significantly lower carotenoids, especially in ‘Alphonso’ cultivar. In non-wrapped fruit, the carotenoids increased to only 1,363 and 614 µg/100 g in these cultivars respectively, indicating suppression of the normal ripening process due to CI.

Shrink wrapped mangoes of both cultivars exhibited normal ripening with good fruit quality when shifted to ambient temperature after unwrapping. After ripening, the TSS, sugars and carotenoid content further increased significantly and TA decreased in shrink wrapped mangoes compared to non-wrapped fruit (Table 2). The marginal increase in TSS is

mainly due to conversion of remaining starch into sugars which was also reflected by marginal increase in sugars. TSS and total sugars of shrink wrapped fruit (D-955 and LD-935 film) stored at 8 °C were comparable with that observed by Sudhakar Rao and Gopalakrishna Rao (2008) in these cultivars, stored at optimum temperature of 13 °C. However, TSS and total sugars were significantly lower in fruit wrapped with LDPE film compared to other films, but significantly higher than non-wrapped fruit. This indicates that total sugars were not affected, even after 5 weeks at 8 °C, when the fruit were shrink wrapped with suitable semi-permeable films. Shrink wrapped fruit did not lose the ability to metabolise acids both during storage and ripening, which is one of the adverse effects of CI. Storage of ‘Kensington’ mangoes at chilling temperatures of 1, 5 and 10 °C caused ripened fruit to have lower pH and higher TA than those stored at 15 or 20 °C (Chaplin et al. 1991). In the same cultivar, O’Hare and Prasad (1993) reported that acid metabolism was affected at chilling temperatures as high as 10 °C and enhanced CO₂ (5 %) alleviated this CI symptom.

Due to chilling injury, carotenoid pigment development was very poor in non-wrapped fruit of both cultivars, which was also reflected by lower pulp chroma values of these cultivars (Table 2). Thomas (1975) also reported occurrence of maximum inhibition of carotenoid formation on ripening, in ‘Alphonso’ fruit stored continuously at 7 °C for 43 days. Shrink wrapping helped in keeping the mangoes in pre-climacteric stage during 5 weeks at 8 °C, thereby avoiding the effect of CI on carotenoid synthesis during post-storage ripening process. This was also reflected by the typical pattern of climacteric behaviour observed in wrapped fruit (Figs. 1 and 2) during ripening under ambient conditions, after storage at 8 °C. Among different shrink films, mangoes of both

cultivars wrapped with LD-935 and D-955 films had significantly higher carotenoid content (Table 2). In both cultivars, carotenoid content was significantly lower in fruit wrapped with LDPE film compared to other two films, but still significantly much higher than non-wrapped fruit. The pulp colour of both cultivars was darker in the fruit packed with LD-935 film with higher chroma values that was also reflected by high carotenoid content in this treatment compared to the other two films.

After ripening, vitamin C content was significantly lower in non-wrapped fruit in both cultivars compared to shrink wrapped fruit (Table 2). As CI symptoms in mango appeared only after removal from 8 °C, the loss in ascorbic acid content in non-wrapped fruit could be attributed to the low temperature stress. The loss of ascorbic acid might be possibly to combat chilling induced oxidative stress in the fruit. Chilling temperatures enhance AOS (active oxygen species) proliferation and reduce the scavenging efficiency by inactivation of antioxidants and/or impeded antioxidant turnover. Chilling temperatures alter the equilibrium between AOS generation and defence mechanism causing oxidatively induced CI (Hodges et al. 2004). In the present study, shrink wrapping alleviated the CI and was found to be effective in preventing the losses in ascorbic acid content. Low permeability of shrink films to oxygen during storage might have suppressed the activity of oxidative enzymes that are responsible for the oxidation of ascorbic acid. Singh and Sudhakar Rao (2005b) also reported the positive effect of optimum MA packing conditions on retention of ascorbic acid in mature green ‘Solo’ papayas stored at 7 or 13 °C for 20 or 30 days, followed by ripening in air at 20 °C. Among different films, the vitamin C content was significantly higher in mangoes (both cultivars) shrink wrapped with D-955 film (Table 2), that is less permeable to both oxygen and carbon dioxide. The vitamin C content of LDPE wrapped fruit was on par with that of LD-935 film wrapped fruit in both cultivars.

Antioxidant levels Antioxidant quality of the fruit was analyzed after 1 week of ripening at room temperature following 5 weeks at 8 °C (Table 3). In ‘Alphonso’ cultivar, total antioxidant capacity (FRAP), DPPH radical scavenging ability and total phenols were significantly higher in non-wrapped fruit compared to fruit wrapped with different films. However, higher flavonoids were observed in the shrink wrapped fruit when compared to non-wrapped fruit. Among the films, fruit wrapped with LD-935 recorded higher FRAP and DPPH values in ‘Alphonso’ cultivar and in case of ‘Banganapalli’ cultivar, FRAP and DPPH values were higher in fruits wrapped with D-955 and LD-935 films respectively. Fruit wrapped with LDPE film recorded significantly lower antioxidant among all the treatments in both cultivars. Total antioxidant capacity determined in terms of FRAP and DPPH is a combination of total phenols, flavonoids, ascorbic acid and

total carotenoids. Relatively higher antioxidant activity in LD-935 treatment was probably due to higher carotenoid content when compared to D-955 film. Higher antioxidant capacity in non-wrapped fruit was mainly due to the higher total phenol content, which was not reduced due to inhibition of ripening in these fruit. This was also reflected by the higher TA and lower carotenoids observed in these non-wrapped fruit compared to fruit wrapped with different films (Table 2). Higher total phenols were also reported in ‘Irwin’ mangoes stored at 5 °C when compared to fruit ripened at 25 °C (Shivashankara et al. 2004). Inhibition of polyphenol degradation was reported to result in the higher antioxidant capacity in CA stored mangoes (Kim et al. 2007). Minor changes in antioxidants during low temperature storage were reported even though other quality parameters like total carotenoids and TSS declined significantly (Talcott et al. 2005).

Sensory quality Ripe fruit were evaluated for sensory quality after 5 weeks at 8 °C followed by one week ripening under ambient conditions. Shrink wrapped fruit of both cultivars registered significantly higher scores for all the sensory parameters evaluated, viz., fruit appearance, pulp colour, pulp texture and flavour qualities when compare to non-wrapped mangoes (Table 4). Among different films used for shrink wrapping, the sensory qualities of both cultivars were better in the fruit wrapped with D-955 film (>4.0 out of 5.0 score for all parameters) followed by LD-935 film. The highest score of above treatments could be attributed to better retention of quality by shrink wrapping as discussed earlier. Sensory evaluation panel did not report any off-flavour in shrink wrapped fruit.

Ripening behaviour Both shrink wrapped or non-wrapped ‘Alphonso’ and ‘Banganapalli’ mangoes were unripe, firm and remained green without any surface colour development, even after 5 weeks at 8 °C. External visual CI symptoms were not observed in both cultivars stored for 5 weeks at 8 °C. Sudhakar Rao and Gopalakrishna Rao (2009) also did not observe any external visual CI symptoms in same cultivars even after 6 weeks at 8 °C, either in CA or in air. In ‘Kensington’ mangoes also, skin browning was apparent only at 5 °C but not at 7 or 10 °C even after 5 weeks (O’Hare and Prasad 1993). However, shrink wrapped fruit were more fresh in appearance without any shrivelling than the non-wrapped fruit, that were dull in appearance with slight shrivelling of peel. Upon transfer to ambient conditions (24–32 °C and 60–70 % RH), shrink wrapped fruit ripened normally within a week with good surface yellow colour, edible softness and without any CI symptoms. The positive effect of shrink wrapping in alleviation of CI has also been reported by Singh and Sudhakar Rao (2005a) in papaya. Although CI symptoms were not apparent in non-wrapped fruit during 8 °C storage, upon transfer to ambient condition, these fruit

Table 3 Effect of shrink wrapping on the antioxidant content of mango stored for 5 weeks at 8 °C followed by 1 week ripening at ambient conditions (24–32 °C and 60–70 % RH)

Cultivar/Shrink Film	FRAP, mg AEAC*/100 g	DPPH, mg AEAC/100 g	Total phenols, mg GA** equi./100 g	Total flavonoids, mg catechin equi./100 g
‘Alphonso’				
D-955 film	110.95 ^e ±8.23	289.10 ^f ±5.80	72.76 ^{de} ±1.60	3.05 ^f ±0.16
LD-935 film	131.15 ^f ±1.45	318.31 ^g ±3.30	70.94 ^d ±3.38	2.82 ^e ±0.14
LDPE film	105.61 ^d ±2.54	249.98 ^e ±6.67	58.33 ^b ±2.03	2.10 ^d ±0.12
Non-wrapped	141.44 ^g ±7.06	333.86 ^h ±10.83	86.25 ^f ±5.43	1.99 ^c ±0.12
‘Banganapalli’				
D-955 film	44.28 ^c ±1.92	138.15 ^b ±6.51	73.64 ^e ±2.03	1.05 ^b ±0.14
LD-935 film	40.87 ^{bc} ±2.72	152.35 ^d ±1.84	62.15 ^c ±4.95	1.03 ^b ±0.18
LDPE film	25.81 ^a ±3.76	101.57 ^a ±5.00	53.42 ^a ±3.34	0.68 ^a ±0.07
Non-wrapped	39.03 ^b ±4.88	129.23 ^c ±5.82	61.25 ^c ±1.45	0.98 ^b ±0.17
LSD (<i>P</i> <0.05)	11.52	20.81	7.01	0.33

Means within the same column and section with different superscripts are significantly different (*p*<0.05). Each value is the mean for five replicates

*AEAC is Ascorbic acid equivalent antioxidant capacity, ** GA – Gallic acid

failed to ripen properly with CI symptoms of uneven ripening and shrivelling. Sudhakar Rao and Gopalakrishna Rao (2009) also made similar observations in same cultivars after 6 weeks at 8 °C. Irrespective of the packaging treatment, anthracnose incidence (the common post harvest disease in mango) was not observed after storage or during ripening in both cultivars. This is mainly attributed to the post harvest fungicide treatment given before storage. The effectiveness of post harvest fungicide (ProchlorazTM) treatment in controlling the spoilage in CA or air-stored mangoes was also reported earlier by Sudhakar Rao and Gopalakrishna Rao (2009) in the same

cultivars. However, a negligible incidence (<1) of stem end rot incidence was noticed especially in ‘Alphonso’ cultivar.

Conclusion

‘Alphonso’, and ‘Banganapalli’ cultivars of mangoes shrink wrapped with D-955 film (15 µm) could be stored for 5 weeks at 8 °C in unripe green condition. These cultivars were reported to be fully ripe respectively by 21 and 25 days itself at optimum low temperature storage of 13 °C (Sudhakar Rao

Table 4 Organoleptic quality of shrink wrapped mango stored for 5 weeks at 8 °C followed by 1 week ripening at ambient conditions (24–32 °C and 60–70 % RH)

Cultivar/Shrink Film	Organoleptic score*				
	Appearance	Pulp-colour	Pulp-texture	Flavour	Overall acceptability
‘Alphonso’					
D-955 film	4.15 ^f ±0.06	4.20 ^g ±0.08	4.11 ^f ±0.08	4.03 ^c ±0.24	4.12 ^g ±0.07
LD-935 film	3.82 ^d ±0.16	4.06 ^f ±0.12	3.96 ^c ±0.04	3.69 ^d ±0.02	3.88 ^c ±0.16
LDPE film	3.63 ^c ±0.18	3.65 ^c ±0.25	3.75 ^c ±0.07	3.45 ^b ±0.20	3.62 ^c ±0.12
Non-wrapped	2.35 ^b ±0.22	2.83 ^b ±0.07	2.59 ^b ±0.10	2.51 ^a ±0.24	2.57 ^b ±0.20
‘Banganapalli’					
D-955 film	4.12 ^f ±0.11	4.04 ^f ±0.35	4.05 ^f ±0.19	4.01 ^c ±0.28	4.05 ^f ±0.04
LD-935 film	4.03 ^c ±0.05	3.98 ^c ±0.31	3.89 ^d ±0.24	3.73 ^d ±0.09	3.91 ^c ±0.13
LDPE film	3.99 ^c ±0.25	3.88 ^d ±0.11	3.80 ^c ±0.03	3.59 ^c ±0.16	3.82 ^d ±0.17
Non-wrapped	2.17 ^a ±0.24	2.52 ^a ±0.30	2.46 ^a ±0.31	2.50 ^a ±0.30	2.41 ^a ±0.16
LSD (<i>P</i> <0.05)	0.26	0.25	0.27	0.30	0.21

Means within the same column & section with different superscripts are significantly different (*p*<0.05)

Each value is the mean for ten replicates

* 1, very bad; 2, poor; 3, fair; 4, good; 5, very good

and Gopalakrishna Rao 2008). After unwrapping, these shrink wrapped fruit ripened normally within a week at ambient temperature (24–32 °C and 60–70 % RH) without any chilling injury symptoms and normal respiratory behaviour. After ripening, both varieties of mangoes showed good surface yellow colour development, higher TSS, sugars, vitamin C and carotenoid contents with acceptable organoleptic quality. On the other hand the non-wrapped fruit stored at 8 °C fail to ripen properly, with CI symptoms of uneven ripening, shrivelling and harder pulp texture with poor carotenoid pigment development, when shifted to ambient temperature.

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