EFFECT OF MODIFIED ATMOSPHERE PACKAGING ON THE POSTHARVEST LIFE AND QUALITY OF MANGO CV. SAMAR BAHISHT CHAUNSA STORED AT CHILLING TEMPERATURE

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Modified Atmosphere Packaging (MAP) increases the postharvest life of fresh fruits by suppressing metabolic activities with modified in-package atmosphere. This study was aimed to explore the potential benefits of MAP technology combined with low temperature storage in mango cv. 'Samar Bahisht Chaunsa' to extend its shelf life. Physiologically mature mangoes after harvest were de-sapped (0.5% lime solution), dipped in hot water ($52\pm2°C$ for 5 min) fungicidal (0.5 mL Prochloraz L^{-1}) solution, packed in 5kg cardboard boxes (T_1; Biofresh®, T_2; Xtend®, T_3; Unbagged) and stored at 13°C±1, RH: 85-90% for 7, 14, 21, 28 and 35 days. Following cold storage, fruit were subjected to two different ripening temperatures (32 and 24°C) with a 24 h 100 ppm ethylene treatment. Data related to physical, physiological, biochemical, organoleptic and marketable attributes was collected. Among MAP bags, the desirable atmosphere comprising high CO_2 and low O_2 concentration was observed in Biofresh® bags. Tolerance of mangoes under elevated CO_2 atmospheres and chilling injury (CI) decreased when storage period exceeded more than 14 days with onset of discolouration issues. Overall, bagged fruit had minimum weight loss, CI intensity, shriveling and remained firmer in comparison to control. Maximum peel colour development was observed in fruit stored up to 14 days in Biofresh® bags when ripened at high temperature ($32\pm1°C$). Whereas, fruit kept in Xtend® bags and those without MAP only developed acceptable peel colour up to 7 days of cold storage. Fruit kept in Xtend® bags exhibited minimum ethylene levels (ppm) and endured the least loss in weight and firmness but remained mostly green. Bagged fruit had a higher vitamin C content and lower TA in comparison to unbagged fruits. In conclusion, 'Samar Bahisht Chaunsa' stored at 13°C in Biofresh® bag showed better visual appearance, palatability and nutritive values as compared to Xtend® bag and those without MAP.
Keywords: Mango, chilling injury, MAP, skin discoloration, shelflife, quality.

INTRODUCTION

Mango is reputed as the king of fruits in the world due to its ever desiring flavour, high nutritive value and appealing appearance (USDA, 2013). It is the 2nd most important fruit crop of the Pakistan with annual production of 1.7 million tons, and export earnings of 43.6 million dollars (Anonymous, 2015). 'Samar Bahisht Chaunsa' a mid-season commercial cultivar, is the most popular mango, predominantly grown in Punjab province. The ripe fruit is canary yellow to raw sienna in colour with a firm flesh and sweet flavour.

Mangoes are highly demanded in both domestic and international markets provided that quality is maintained on reaching the destination. Being climacteric fruit, short shelf life accompanied with poor fruit quality limits its export from Pakistan to high end markets. Among fruit quality issues, uneven ripening including poor fruit skin colour development, sap burn injury and chilling injury (CI) cause significant reduction in price with repute in the international export markets (Malik and Mazhar, 2007). Fruit quality is influenced by several integrated factors including pre-harvest

farming practices (management of canopy, nutrition, irrigation, orchard floor, pest and diseases) and postharvest handling operations particularly storage.

Mangoes under ordinary long term cold storage are susceptible to CI (Hafeez *et al.*, 2012). To improve quality and stretch the postharvest life span of mango, alternative storage technologies including controlled atmosphere (CA) and modified atmosphere packaging (MAP) need to be tested and optimized.

MAP technology is popular in the world for its potential to extend mango shelf life with better maintained quality in comparison to ordinary cold storage. Exotic cultivars including 'Keitt', 'Tommy Atkins', 'Kensington Pride' and 'Nam Dok Mai' have been reported to benefit under MAP with delayed ripening, reduced shriveling and better appearance with an extended shelf life (Sornsrivichai *et al.*, 1989; Smith and Jordan, 1992). Mangoes under adequate gas compositions (high CO_2 and low O_2) and optimum storage conditions (RH and temperature) suspend physiological and biochemical processes related to ripening and combat several disorders (Prusky and Keen, 1993). Mango cv. Samar Bahisht

Chaunsa exhibited uneven ripening with symptoms of CI, discolouration when stored at 12-13°C during long term storage as compared to mango cvs. Sindhri and Sufaid Chaunsa (Amin, 2012). Similarly, Yahia (2011) also reported sensitivity of 'Keitt', 'Haden' and 'Sensation' mangoes to CI. However, MAP has been reported to ameliorate CI symptoms in chilling sensitive crops and inhibit ethylene biosynthesis with elevated CO_2 and reduced O_2 levels (Pesis *et al.,* 2000; Yahia, 2009).

MAP has also been reported to provide atmospheres which are detrimental to insect and pathogens (El-Goorani and Sommer, 1981; Kader and Ke, 1994). However, MAP technology has not been standardized for quarantine purpose so far due to chances of modified atmosphere injury and consumers concerns. Moreover, atmospheres above 8% CO_2 and below 2% O_2 can cause MA stress, increase off-flavour development and deterioration (Kader, 2008). Therefore, selection of suitable size, film, package type is very important to overcome these issues. Chaplin *et al.* (1982) found that 'Kensington' mango stored in MAP developed un-even ripening with off-flavours at 20°C than perforated bags.

Despite its worldwide acceptance, MAP is not a very popular technology in Pakistan mainly on account of limited research work in the past. Reported research on MAP has remained variable due to difference in packagings, storage conditions and mango cultivars. At this time, to the best of our knowledge, very limited information is available regarding application of MAP for long term storage of mango cv. Samar Bahisht Chaunsa at low temperature. Under this perspective, the present study was planned to investigate the potential application of MAP technology in this important commercial Pakistani mango cultivar with an emphasis on improved postharvest life with best fruit quality.

MATERIALS AND METHODS

Uniform green mangoes cv. Samar Bahisht Chaunsa were harvested along with pedicels at the appropriate maturity stage from a commercial orchard (Ali Tareen Farm) located in district Lodhran, Pakistan (latitude: 31° 19′ 48″ N; longitude: 74° 12′ 36″E). After harvest, fruit were de-sapped using 0.5% lime solution (Amin *et al.*, 2008), followed by a fungicidal mixed (0.5 mL Prochloraz L^{-1}) hot water dip at 52°C for 5 min. After treatment, fruit were air dried under shade, packed in corrugated fiberboard boxes, pre-cooled to 18±1°C and transported in reefer van (18±1°C) to Postharvest Research and Training Center (PRTC), Institute of Horticultural Sciences (IHS), University of Agriculture, Faisalabad (UAF). On arrival at PRTC, fruit (6 per experimental unit) were packed in single layer in 5kg cardboard boxes with an average weight of 3.25kg according to the following treatments: T_1: Biofresh® bags (Active Pack International, USA); T_2: Xtend® bags (StePac L.A. Ltd); T_3: Unbagged. Fruit were stored at 13°C±1; 85-90% RH for five

different storage periods (7, 14, 21, 28 or 35 days). Observations were made at three post storage stages (*i.e.* removal day, 48 h after ethylene treatment and at ripe stage). In-package atmospheres were created using ordinary air (CO_2; 0.02% and O_2; 19%). Specially designed valves (Van Amerongen CA Company, The Netherlands) were installed on the packages for monitoring gases. During storage, the level of gases (CO_2 and O_2) accumulated within each type of package were measured using a digital dual gas analyzer (ICA350, UK) after an interval of two days. The gas concentrations for each storage interval was recorded in percentage (%) values while ethylene levels were measured in (ppm) using a digital ethylene meter (ICA56 Digital Ethylene Meter). In addition, using the same device, ethylene production from fruit was calculated in mmol C_2H_4 $kg^{-1}h^{-1}$ for all post storage stages.

On removal day, bags were removed and fruit were subjected to two different ripening conditions (32°C+24h 100 ppm ethylene treatment) and (24°C+24h 100 ppm ethylene treatment). Ethygen was used in the ethylene generator (EASY-RIPE® Catalytic Generators, LLC, Norfolk, Virginia, USA) to generate ethylene into the ripening chambers. After 24 h, fruits were taken out into ambient conditions following the described temperatures until exceptional peel colour developed. Later on, fruits were shifted to a shelf temperature of 22±2°C until they became eating soft to determine biochemical, organoleptic and marketable attributes.

Fruit peel colour development (1: 100% green and 0% yellow, 2: 75% green and 25% yellow, 3: 50% green and 50% yellow, 4: 25% green and 75% yellow and 5: 0% green and 100% yellow) and softness (1: hard, 2: sprung, 3: slightly soft, 4: eating soft and 5: over ripe) was rated according to score scale of Anwar *et al*. (2008). Discolouration/CI (1: Nill; 2: 25%; 3: 50%; 4: 75%; 5: 100%) and shriveling (1: Nill; 2: <10%; 3: 10-25%; 4: 25-50%; 5: >50%) was recorded on the basis of self-made rating scales whereas disease incident (anthracnose, body rot and stem end rot) was recorded as described by Amin *et al*. (2011).

Total soluble solids (SSC) were determined using Atago RX 5000 Digital Refractometer (Atago, Japan). Titratable acidity (TA) was determined by method of Hortwitz (1960) while vitamin C (mg 100g^{-1}) was determined as described by Ruck (1969). Organoleptic evaluation of fruit was done by a panel of ten judges, using the hedonic scale (Peryam and Pilgrim, 1957).

Marketable index (MI) was developed using a self-made scale (1: bad; 2: good; 3: excellent). Marketable fruit (MF) percentage was calculated on the final day. Fruits that developed rot or had external defects with severity (CI, discolouration, shriveling) were considered as unmarketable fruits.

The experiment was laid out under CRD factorial arrangement (storage days, ripening temperature) with four

replications. Statistical analysis of collected data and Karl Pearson's Complete Correlation analysis was performed using Statistix® software (version 8.1) (Kovach, 2007). Significance of data was evaluated with the help of analysis of variance method. The difference among treatment means were checked by following Least Significant Difference (LSD) test at 5 % level of significance (Steel *et al.*, 1997)

RESULTS AND DISCUSSION

Physiological Attributes:

In-package gas concentration: Both type of bags had different in-package atmospheres which significantly changed with prolonged storage period (Fig. 1A). In addition, a direct relation between ethylene levels and storage period was observed with a pronounced ethylene peak at a storage period of 28 days (Fig. 1B). Gonzalez *et al.* (1990) reported that ethylene usually accumulates inside the package as storage period progresses. Highest levels of mean CO_2 (11.68%) and C_2H_4 (8.6 ppm) while lowest O_2 levels (9.46 %) were monitored in the atmosphere surrounding the packed fruit in T_1 (Biofresh®) (Fig. 2).
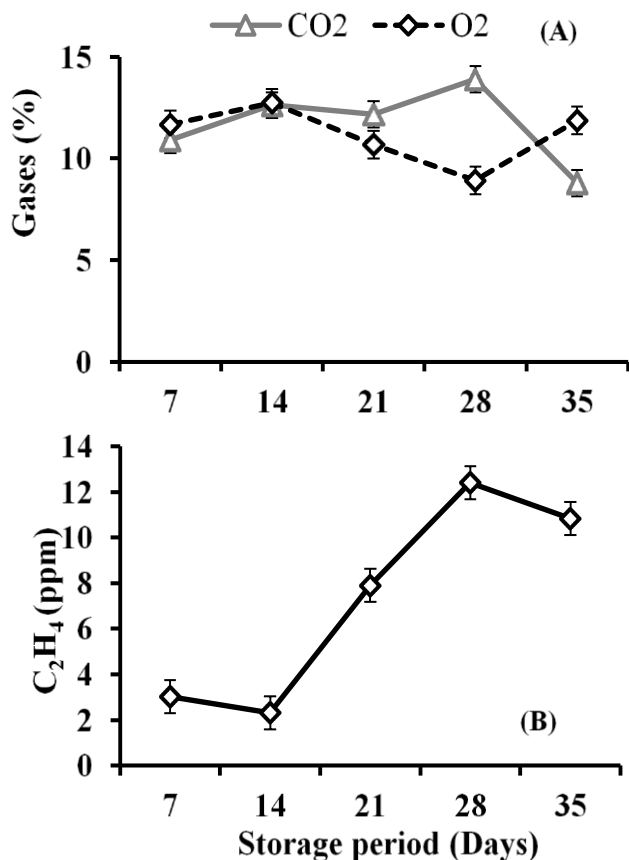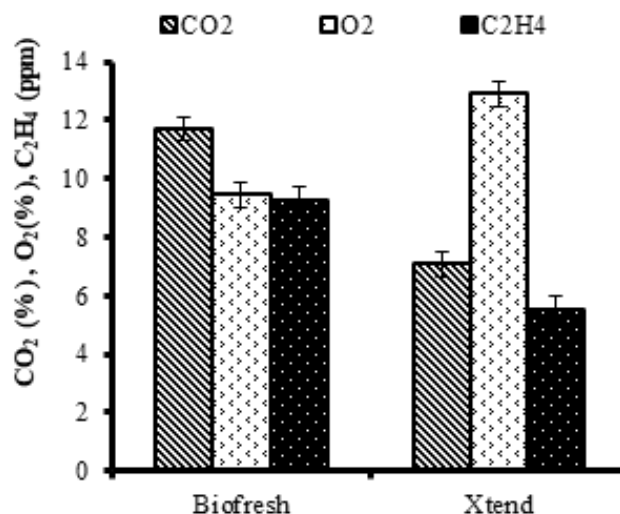

Figure 2. **Mean levels of in-package CO_2 (%), O_2 (%) and C_2H_4 levels (ppm) during cold storage.** Vertical bars represent ± SE of means; n = 4 replicates.

Alternatively, T_2 (Xtend®) exhibited significantly lower mean levels of CO_2 (7.06%) and C_2H_4 (5.9 ppm); while, higher O_2 levels (12.91%). A negative correlation (r = -0.915) was observed between in-package CO_2 and O_2 levels (Table 1). As storage period progressed, CO_2 levels exhibited an increased trend; whereas, O_2 levels declined but remained within the reported safe range (5-7%) that avoids off flavours (Table 2) (Yantarasri *et al.*, 1995). However, CO_2 concentration in T_1 (Biofresh®) was found to be above the reported tolerable range (5-10%) for mango and long term exposure to such atmospheres increases susceptibility to MA injury. Overall, both bags were proven to be very effective in retarding ethylene development. Combination of low temperature storage and continuous flushing of ethylene through the bags may have been responsible for low ethylene levels. In T_2 (Xtend®) bags, the ethylene levels were generally low in comparison to T_1 (Biofresh®) bags. High CO_2 atmospheres have been reported to inhibit ethylene production by many authors. Despite relatively low CO_2 and high O_2 levels, T_2 (Xtend®) was found to be more effective in retarding ethylene build up possibly due to a slower respiration rate and effective exclusion of C_2H_4 by the package. Another important factor to account is the in-package humidity. Hatton and Spalding (1990) reported that certain positive effects could be induced as a result of a maintained humid atmosphere around the fruit instead of modified gases alone. Pesis *et al.* (2000) reported that fruit packed in films with low RH (88.2%) accelerated ripening and produced higher levels of CO_2 and ethylene as compared to those packed in films with high RH (95.3%). There is a possibility that T_1 (Biofresh®) had higher CO_2 and ethylene levels as compared to T_2 (Xtend®) because of a lower humidity within the package.

Figure 1. **(A) In-package CO_2 and O_2 levels (%) and (B) C_2H_4 levels (ppm) during cold storage.** Vertical bars represent ± SE of means; n = 4 replicates.

Table 1. Correlation analysis between in-package gases (CO_2, O_2) and colour parameters.

Correlation parameters	Result	Trend	Probability value
CO_2 vs O_2	Significant	-ive	0.0000
CO_2 vs Peel colour	Non-significant	--	0.3298
O_2 vs Peel colour	Non-significant	--	0.5269
CO_2 vs Discolouration	Non-significant	--	0.4463
O_2 vs Discolouration	Significant	-ive	0.0365
Peel colour vs Discolouration	Significant	-ive	0.0000

Significant at $P \leq 0.05$

Table 2. In-package gas levels at all storage periods.

| Storage period (days)	Biofresh® (T_1)			Xtend® (T_2)		
	CO_2 (%)	O_2 (%)	C_2H_4 (ppm)	CO_2 (%)	O_2 (%)	C_2H_4 (ppm)
7	10.9b	10.5e	3.9cd	7.9cd	12.8bc	2.1de
14	12.6ab	10.4e	3.0cde	6.0de	15.0a	1.6e
21	12.1ab	8.0f	11.0b	5.7e	13.3ab	4.7c
28	13.9a	7.0f	14.5a	8.7c	10.8de	10.3b
35	8.8c	11.2cde	10.8b	7.0cde	12.5bcd	10.8b

Means not sharing similar letters are significantly different ($P \leq 0.05$).

*Weight loss***:** Percentage of fruit weight loss progressively increased with storage (Fig. 3). As expected, the maximum weight loss percentage was observed at the full ripe stage as compared to removal day or after ethylene exposure (Fig. 4A).
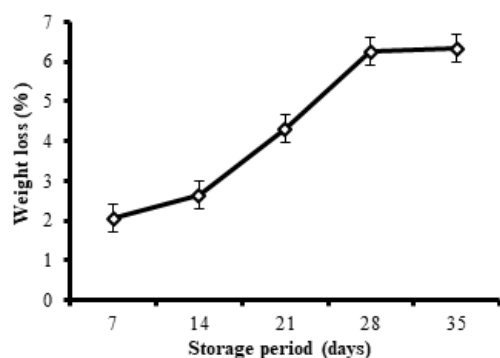
Figure 3. Mean values of fruit weight loss during cold storage. Vertical bars represent ± SE of means; n = 4 replicates.

During storage, T_2 (Xtend® bags) showed the least weight loss percentage while T_3 (Unbagged) showed the highest and T_1 (Biofresh® bags) remained in between other treatments. Significant reduction in weight loss through MAP application has been reported earlier (Gonzalez *et al.*, 1990). Moisture loss through lenticels, stomata and openings result in weight loss and shriveling. It occurs when relative humidity (RH) in the environment surrounding the fruit is less than the (RH) inside the fruit (Brecht and Yahia, 2009). Reduced weight loss in T_2 (Xtend®) during storage could have been due to a much higher in-package humidity surrounding the fruit than T_1 (Biofresh®). Unbagged fruit in open atmospheric storage conditions (ambient air) had no hindrance against moisture

loss which resulted in the highest weight loss during storage. Bagging seemed to remain effective in substantially reducing weight loss during storage but did not significantly differ after initiation of ripening or the final day. High temperature ripening resulted in a comparative greater loss in weight.
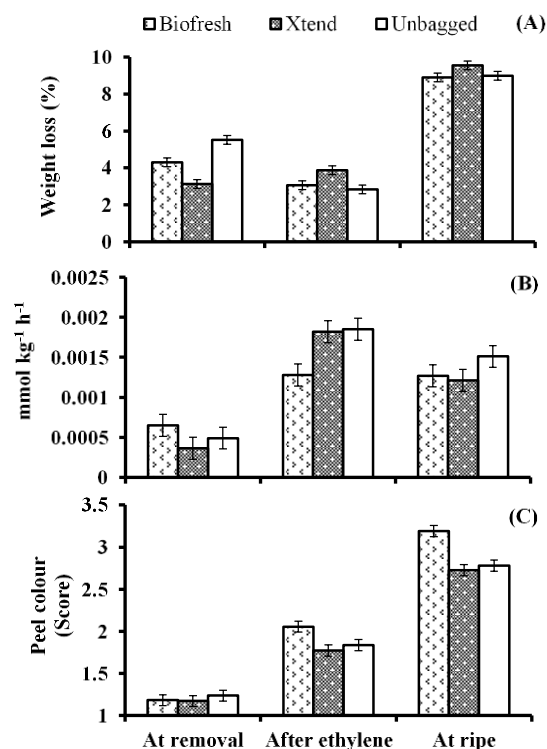
Figure 4. Effect of treatments on (A) weight loss, (B) ethylene production and (C) peel colour development at all stages. Vertical bars represent ± SE of means; n = 4 replicates.

Fruit ethylene production (mmol C_2H_4 $kg^{-1}h^{-1}$): Ethylene remained quite stable on the removal day for each storage interval and increased at the last two storage periods. On removal day, ethylene was found to be minimal in fruits kept in T_2 (Xtend® bags) which shows the possibility of a much reduced rate of metabolic activity (respiration and transpiration) in comparison to T_1 (Biofresh® bags) and T_3 (Unbagged) (Fig. 4B). Among stages, fruits showed the highest ethylene production during ripening stage followed by fully ripe stage and removal day. Unbagged fruits exhibited the highest rate of ethylene production at fully ripe stage in comparison to bagged ones, possibly due to an earlier initiation of the senescence process. Mangoes produce moderate rates of ethylene (1-2µL kg^{-1} h^{-1}) at 20°C (Lakshminarayana, 1973). Ethylene rate was observed to be much higher in fruits that were ripening at high temperature (32°C), as compared to low temperature (24°C).

Physical Attributes:

Peel colour development: Optimum peel colour is a very important fruit quality parameter that determines consumer preference and acceptability. All results regarding peel colour development were statistically significant along with their interaction. Fruits remained green during storage regardless of treatments and started to develop colour after ethylene exposure with the maximum colour score at ripe stage (Fig. 4C). The unbagged fruits were also green on removal day during all storage periods which implies that low temperature storage conditions aided in reducing loss of chlorophyll. Among treatments, T_1 (Biofresh®) showed the highest peel score followed by T_3 (Unbagged) and T_2 (Xtend®) during ripening and at ripe stage. Fruits bagged under T_2 (Xtend®) mostly remained green with the lowest post ripening peel colour score that may be ideal for green cultivars only. Srinivasa *et al.* (2002) reported that elevated CO_2 levels prevented yellow colour development by inhibition of carotenoid synthesis. However, a non-significant correlation was found between in-package gases (CO_2 and O_2) and post storage peel colour at ripe stage. Besides low peel colour, fruits under T_2 (Xtend®) showed lesser loss in weight and remained firmer with the lowest C_2H_4 levels (ppm) during storage which shows a much reduced metabolic activity that may have been influenced by a higher in-package RH. In the trial, fruit bagged under T_1 (Biofresh®) for 14 days in cold store gave the best post ripening peel colour score (Table 2). But after 21 days of storage, peel colour regardless of treatments kept declining till the end of cold storage period. Imposition of post storage peel colour development at ripening due to long term storage seems to be an inheriting varietal characteristic of cv. Samar Bahisht Chaunsa. Similarly, Amin (2012), also reported that prolonged storage under chilling temperature had negative effects on the peel colour development. Unbagged fruits (T_3) were only able to develop full yellow post storage peel colour (80%) when storage duration did not exceed 7 days. After 14 days of

storage, fruit bagged under T_1 (Biofresh®) packaging showed the highest yellow score for peel (80-85%) followed by unbagged fruits (T_3) (65%) and those under T_2 (Xtend®) (55-60%) at full ripe stage (Fig. 5). Fruit ripening at high temperature developed better and quicker peel colour as compared to the ones at low temperature (Data not shown). However, no significant difference was seen at the last two storage periods as prolonged storage negatively influenced ripening at either temperature.
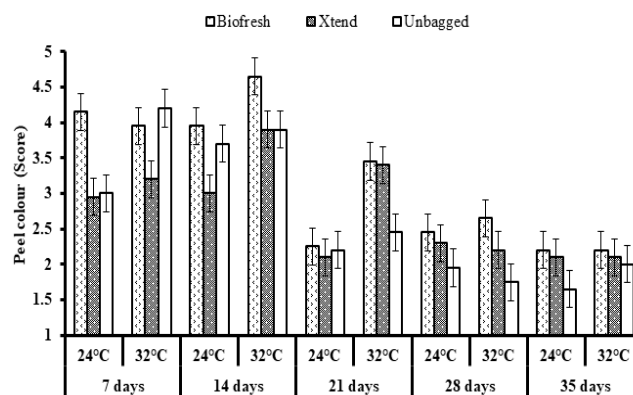

Figure 5. Interactive effect of ripening temperatures and storage periods on peel colour development at ripe stage. Vertical bars represent ± SE of means; n = 4 replicates.

Discolouration/CI: Considering removal day, CI appeared after 21 days in storage (13°C±1) with much higher intensity in fruits without MAP (T_3) followed by bagged fruit (T_3) and under Xtend® (T_2) packaging (Fig. 6A). Whereas, fruit under Biofresh® bags (T_1) alleviated CI possibly because of elevated in-package CO_2 levels which coincides with earlier reports by O'Hare and Prasad (1993). At the last two storage periods, all fruit irrespective of MAP treatment were chill injured on the removal day. The highest discolouration score was detected at fully ripe stage followed by ethylene exposure and removal day. Furthermore, post storage peel discolouration during ripening was found to be higher in fruits bagged under T_1 (Biofresh®), followed by T_2 (Xtend®) and T_3 (Unbagged). Discolouration in unbagged fruit as a result of CI disorder appeared as red spots on the surface of fruit with some extent of browning. CO_2 discolouration in bagged fruits was mostly apparent after ripening in the form of irregular green patches all over the fruits surface which were actually areas that failed in breaking down chlorophyll or synthesizing carotenoids. However compounding injury (CO_2 + CI) was visible in fruits at the last two storage periods which was difficult to distinguish. The highest peel and lowest discolouration score was recorded in fully ripe fruits from storage periods of 7 and 14 days. But as storage period passed, fruit showed a decreasing trend in peel colour development whereas discolouration increased rapidly (Fig. 6B). Correlation

analysis revealed a negative trend (r = -0.634) between peel colour and discolouration (Table 1). Moreover, a negative correlation (r = -0.331) was found between in-package O_2 levels and discolouration.
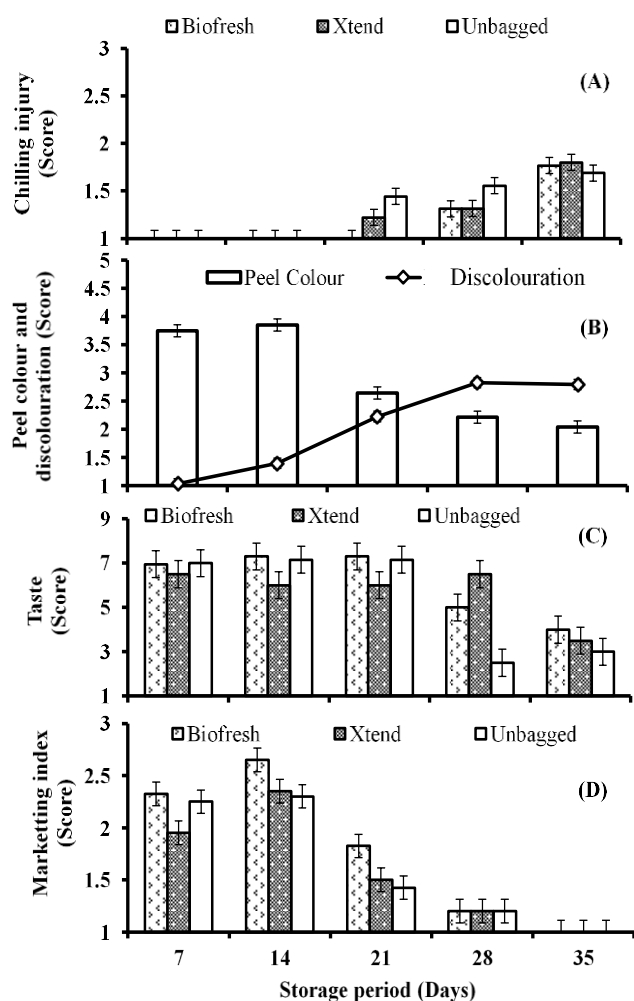

Figure 6. Effect of bagging treatment on (A) chilling injury, (B) peel colour and discouration, (C) taste and (D) marketing index during cold storage. Discolouration/CI at removal stage. Vertical bars represent ± SE of means; n = 4 replicates.

This highlights that discolouration increased as in-package O_2 levels decreased with progress in storage period. Yantarasri *et al.* (1995) noted that 'Nam Dok Mai' mango failed to develop peel colour under low oxygen level (<6%) due to poor permeability of seal-package. In-package O_2 levels in this study were found to be safer than the reported levels to induce disorders while CO_2 levels were very high (Table 2). However, CO_2 and O_2 tolerance range for 'Samar Bahisht Chaunsa' may differ. Unbagged fruits kept in storage for uptill 7 days at 13°C showed good peel colour development after ripening without discolouration/CI issues. With this

exception, post storage peel colour development in unbagged fruit remained extremely poor during the remaining storage periods with CI disorders. Similar situation was observed in fruits bagged under T_2. However, fruits bagged under T_1 showed better potential in cold storage (14 days) by giving the highest peel colour when ripened with negligible discolouration issue**.**

*Firmness***:** During storage, fruit softening initiated after 21 days and continued till the end of cold storage with maximum softening score in fruits without MAP**.** Fruit in open atmospheric storage conditions have been reported to endure a rapid reduction in textural firmness as a result of accelerated ripening processes (Kelany *et al.*, 2010). Bagged fruit remained considerably firmer during storage as elevated CO_2 and reduced O_2 concentrations aid in preventing undesirable textural changes including softening (Fig. data not sown) (Lougheed and Dewey, 1966). Among the packages, T_2 (Xtend®) was found to remain firmer in comparison to T_1 (Biofresh®). In climacteric fruits, ethylene triggers ripening and activates hydrolases to disassemble the cell wall leading to softening (Vidhu *et al.*, 2005). In-package ethylene levels (ppm) and fruit ethylene production (mmol C_2H_4 $kg^{-1}h^{-1}$) was considerably low in Xtend® bags which seems to be a major reason for retention of firmness (Table 2, Fig. 1B). After ethylene treatment, softening was triggered with maximum softening score in fruits without MAP which resulted in a shorter shelf life in comparison to bagged fruits. Fruit that were ripened at high temperature were softer than the ones at low temperature. Hatton *et al*. (1965) observed a direct relation with softening rates and ripening temperature in mango fruit.

*Skin shriveling***:** Shriveling was recorded on the final day when fruit had become eating soft. Moisture evaporation from the fruit causes loss in weight and shriveling. In order to avoid shriveling, fruit were kept in boxes surrounded by a newspaper wrap. The maximum shriveling score was frequently observed in unbagged fruits (T_3) during all storage periods. Among treatments, T_1 (Biofresh®) exhibited the lowest shriveling score while the highest score was observed in T_3 (Unbagged fruits) (Fig. 7A). Bagging was found to be very effective in reducing shriveling. Among ripening temperatures, fruits at high temperature (32°C) had a higher shriveling score as compared to the ones at low temperature (24°C).

*Disease incident***:** During the trial, disease incident remained negligible in either treatment which implies the effectiveness of the fungicidal treatment given prior to the experimentation.

Biochemical Attributes:

*Soluble solid contents (SSC)***:** Total soluble solids of mango fruit were significantly affected by storage periods while treatment and ripening temperatures remained non-significant. The lowest SSC (°Brix) was recorded in fruit removed after a storage period of 35 days (Table 4). Prolonging the storage period might be responsible for the

Table 3. **Effect of treatments, storage durations and their combination on peel colour development at different stages.**

Storage (days)	T₁ (Biofresh®)			T₂ (Xtend®)			T₃ (Unbagged)			Mean
	At RM	After ET	At RP	At RM	After ET	At RP	At RM	After ET	At RP	
7	1.2pq	2.2hij	4.0ab	1.2pq	1.5nop	3.0d	1.3opq	2.0hijk	4.1a	2.3B
14	1.2q	2.9de	4.3a	1.1q	2.0hijk	3.4c	1.2pq	1.9jk	3.8b	2.4A
21	1.1q	1.9ijk	2.8de	1.1q	2.1hij	2.7ef	1.1q	2.0ijk	2.3gh	1.9C
28	1.2q	1.5mno	2.5fg	1.2q	1.6mn	2.2hi	1.2pq	1.5mno	1.8kl	1.6D
35	1.1q	1.6mn	2.2hij	1.1q	1.5mno	2.1hijk	1.2pq	1.6lmn	1.8klm	1.6D
Means	2.1A			1.8B			1.9B			

Means not sharing similar letters are significantly different ($P \leq 0.05$); RM = removal; ET = ethylene treatment; RP = ripe stage

Table 4. Effect of storage duration on the biochemical, organoleptic and marketable attributes of fruit.

Storage period (days)	SSC (°Brix)	TA (%)	Vitamin C (mg/100g)	Taste (Scale)	MI (Score)	MF (%)
7	22.2a	0.16a	62b	6.8a	2.1b	74b
14	22.7a	0.12c	55c	6.8a	2.4a	92a
21	23.1a	0.13bc	72a	6.8a	1.5c	38c
28	21.9a	0.14b	34d	4.6b	1.2d	11d
35	20.2b	0.09d	36d	3.5c	1.0e	11d

Means not sharing similar letters are significantly different ($P \leq 0.05$), SSC = Soluble solid content; TA = titratable acidity; MI = marketing index; MF= marketable fruit.

decline in SSC (°Brix) as a result of degradation. Fruit without MAP did not seem to differ much than the bagged fruits in terms of mean value of SSC (°Brix) (Table 5). However, it was observed that bagged fruits had a slightly higher SSC (°Brix) at the beginning and lower in the final storage period in comparison to the unbagged fruits. The lower value of °Brix in bagged fruit at the last removal could be linked to a reduction in organic acids (TA) (Table 6), since the overall SSC (°Brix) includes organic acids as well. A reduction in TA (%) resulted in increased SSC/acid ratio of bagged fruit compared to control (data not shown).
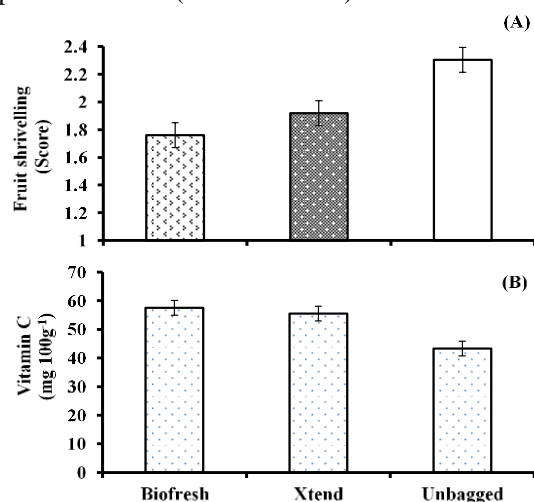
Figure 7. Effect of bagging treatments on (A) fruit shriveling and (B) vitamin C content during cold storage at all stages. Vertical bars represent ± SE of means; n = 4 replicates (Check).

Table 5. **Interactive effect of treatment and storage periods on SSC (°Brix).**

Storage (days)	T₁ (Biofresh®)	T₂ (Xtend®)	T₃ (Unbagged)
7	22.6bcd	23.3abc	20.8d-g
14	23.9abc	24.2ab	20.0efg
21	21.7c-f	22.5bcd	25.1a
28	22.0b-e	21.8c-f	21.8c-f
35	19.1g	19.6fg	22.1b-e
Mean	21.8A	22.3A	21.9A

Means not sharing similar letters are significantly different ($P \leq 0.05$); T₁: Biofresh®; T₂: Xtend®; T₃: Unbagged

Table 6. **Interactive effect of treatment and storage periods on TA (%).**

Storage (days)	T₁ (Biofresh®)	T₂ (Xtend®)	T₃ (Unbagged)
7	0.14bcd	0.18a	0.15b
14	0.12cde	0.11ef	0.14b-e
21	0.12cde	0.11ef	0.15b
28	0.12cde	0.16b	0.15bc
35	0.07g	0.09fg	0.12def
Mean	0.12B	0.13A	0.14A

Means not sharing similar letters are significantly different ($P \leq 0.05$); T₁: Biofresh®; T₂: Xtend®; T₃: Unbagged

*Titratable acidity (TA)***:** Titratable acidity was significantly affected by treatment and storage periods (Table 6) while ripening temperatures remained non-significant (data not shown). Mean TA kept decreasing as storage period progressed with the least percentage at the end of cold storage

(Table 4). Mean TA percentage in unbagged fruit (T_3) was slightly higher than fruit under Biofresh® bags (T_1). Polyethylene bags usually minimize loss in organic acids, but prolonged storage at low temperatures have been reported to cause decrease in acidity percentage due to substantial loss in organic acids (Kelany *et al.*, 2010).

Vitamin C: Long term storage resulted in a sharp decrease in vitamin C content which has been reported earlier (Kelany *et al.*, 2010). Bagged fruits were found to be effective in retaining much higher vitamin C content than unbagged ones (T_3) (Fig. 7B). Exposure of fruit to ambient atmosphere has been reported to cause oxidative reactions responsible for a much higher loss in vitamin C content (Thomas and Oke, 1980). Under MAP, retention of higher vitamin C content has been attributed to lower peroxidase activity in produce due to high CO_2 and low O_2 levels (Galvis *et al.*, 2005). Moreover, in three out of five storage periods, T_1 (Biofresh®) exhibited the highest percentage of vitamin C maybe because of a much higher in-package CO_2 atmosphere during storage. However, prolonged storage followed by ripening caused excessive loss of vitamin C with either atmosphere. In addition, long term storage induced CI in unbagged fruits with more intensity in comparison to bagged fruits which has been reported to decrease accumulation of vitamin C (Chhatpar *et al.*, 1971). There was no significant relation between degree of ripening temperature and vitamin C.

Organoleptic attributes: Storage duration had a significant effect on taste of fruit whereas treatment and ripening temperature remained non-significant. Fruit remained palatable and scored a good taste for uptill 21 days of storage (Table 4). Internally, all mangoes were well ripe with no issue of jelly formation. Despite failure to develop a good external peel colour, T_2 (Xtend®) was internally ripened with a pulp colour ranging from light amber to blood orange with a stable texture. Unbagged fruits exhibited a more fragile texture but had a splendid taste. Fruits under T_1 (Biofresh®) had a delicate texture with an orange pulp colour and mostly attained highest taste scale as par with T_3 (Unbagged) (Fig. 6C). Issues regarding palatability emerged in fruits at the last two storage periods. Fruit off flavour development was not caused by anaerobic respiration. Declining O_2 concentration with progression in storage period was always sufficient and imposition of any deleterious effect on eating quality was unlikely. Poor taste at the end of cold storage implies CI involvement which got severe and unstoppable in either treatment. CI has been reported to induce extreme off flavour and textural impairment in the pulp of mango (Amin, 2012). Fruit also developed visible injury symptoms in terms of discoloured patterns on the pulps surface just beneath the peel without going any deeper. In case of unbagged fruit, pulp seemed very loose in texture with a dark amber colour and exhibited some extent of browning due to prolonged storage in ambient air under chilling temperature.

Marketable Attributes:

Marketable index (MI): Storage periods and treatments had a significant effect on the marketable index (MI) of fruit, whereas ripening temperatures were non-significantly different. MI score remained high for storage periods of 7 and 14 days while a poor score was observed at the end of cold storage (Table 4). The scores were based upon the fruits visual appeal in terms of intensity of peel colour development, ripening uniformity and absence of defects or disorders related to physiology and pathology. The maximum score for MI was observed in fruit under Biofresh® bags (T_1) from a 14 day storage period, while fruit under Xtend® bags (T_2) remained at par with unbagged fruits (T_3) (Fig. 6D). All treatments showed a poor score at the end with no statistical difference.

Marketable fruit (MF) percentage: Storage periods significantly affected the marketable fruit (MF) percentage while treatment and ripening temperatures were insignificant. The highest percentage of marketable fruits was observed in fruits from a 14 day storage period while the least at the end with no marketable fruit (Table 4). Fruits that developed rot or had external defects with severity (CI, discolouration, shriveling) were considered as unmarketable fruits.

Conclusion: This study concluded that storing 'Samar Bahisht Chaunsa' at chilling temperature (13±1°C; RH: 80-95%) under Biofresh® (T_1) packaging for up till 14 days ripened properly at 32°C with maintained fruit quality and an extended postharvest life of 20 days. Fruit bagged under Xtend® (T_2) packaging faced issues in developing the inherent yellow peel colour of the cultivar which discourages its use. Unbagged fruits (T_3) softened earlier resulting in a shelf life shorter than 1-2 days than the bagged fruits. Post storage ethylene treatment (100ppm) for 24 h at 24°C could not induce peel colour development which encourages the use of high temperature ripening for this cultivar, ranging between 30-35°C. Both types of bag had a safe but usually high O_2 concentration (7-13%) which could be lowered by adopting a more controllable approach like active packaging or testing other suitable packages. The lowest tolerable O_2 concentration which does not induce fermentation in this particular cultivar needs to be determined. In addition of CO_2 and O_2 concentrations, water vapour (humidity) needs to be monitored within the package as condensation may lead to incident of diseases if fungicide treatment is not used as a measure of precaution. Moreover, assumption lies that in-package humidity may be a crucial factor influencing behaviour of bagged fruit which requires to be confirmed by scientific testing. Considering these points, MAP technology needs further testing to develop a better understanding of its potential benefits and improve its efficiency.

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