Effect of modified atmosphere packaging and storage conditions on quality characteristics of cucumber

M. Manjunatha · Rahul K. Anurag

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Abstract Cucumbers (*Cucumis sativus* L.) stored in perforated modified atmosphere packaging (MAP) under cold room (4 ± 1 °C and 90 ± 2 % RH) and ambient condition ($23\text{--}26$ °C and $63\text{--}66$ % RH) were evaluated for firmness, weight loss (WL), colour, chilling injury and sensory characteristics. The firmness of cucumbers was decreased to 0.333 and 0.326 N on 6th and 12th day of storage, respectively from initial value of 0.38 N. After 12 days of storage, the WL was in the range of 1.62–12.89 % whereas the cucumber stored under MAP having 2 perforations at 4 ± 1 °C and 90 ± 2 % RH recorded least WL of 1.62 %. The minimum change in colour (Hunter L, a and b values) was observed in the cucumber samples stored at cold room condition. The increase in ‘b’ values (yellowness) was more in the sample stored at ambient condition with unsealed sample registered highest ‘b’ values (35.82). On 12th day of storage, sensory quality evaluation revealed that samples stored under perforated MAP at 4 ± 1 °C and 90 ± 2 % RH were acceptable in condition with sensory score of 7.1 and 7.5. Chilling injury was severe in sample unsealed (4.4 chilling injury score) and slight to moderate chilling injury was observed in 2 and 4 perforated package samples stored under cold room condition. The study revealed that cucumber can be stored under MAP with 2 perforations at 4 ± 1 °C

and 90 ± 2 % RH and ambient condition ($23\text{--}26$ °C and $63\text{--}66$ % RH) for 12 and 6 days, respectively.

Keywords Cucumber · Modified atmosphere packaging · Chilling injury · Quality characteristics

Introduction

Cucumber (*Cucumis sativus* L.) is a major vegetable consumed mainly as salad and pickle. Cucumber is a vegetable used in pickle production in the world (Akbulak et al. 2007) but in developing countries like India it is mainly consumed as salad. Cucumber is a good source of potassium, calcium, vitamin A and K and an excellent cooling vegetable because of its high water content (about 95 %). Cucumber is highly perishable in nature. Cucumbers are very susceptible to shriveling and hence the humidity during storage, transport and marketing should be kept at 90–95 % (Dhall et al. 2010). The main deteriorative changes in cucumber during storage and distribution are mostly due to yellowing, loss of moisture leading to shriveling and physiological injury caused by low temperature (Adamicki 1985). Dhall et al. (2010) reported that cucumber is not suitable for long term storage even at low temperature as it is susceptible to chilling injury at 10 °C or low temperature and yellowing at 15 °C or higher, therefore cucumbers must be stored at temperatures between 10 and 15 °C, whereas Akbulak et al. (2007); Ozer et al. (2006) reported that the optimum temperature range for storage of pickling cucumber cultivars (‘Opera’, ‘Ajax’, ‘Troy’ and ‘Octopus’) could range from 4 °C to 10 °C under different storage atmospheres and the spoilage could be inhibited for 1 week in normal atmosphere, 2 weeks in 5–10 % CO₂ + 3 % O₂, 3 weeks in 15 % CO₂ + 3 % O₂ and 5 weeks in 20–30 % CO₂ regardless of O₂ level. Although spoilage could be controlled for a few weeks in controlled

M. Manjunatha · R. K. Anurag
Food Packaging and Transportation Laboratory,
Division of Agricultural Structures and Environmental Control,
Central Institute of Post Harvest Engineering and Technology,
P.O., P.A.U. Campus,
Ludhiana, Punjab, India 141004

M. Manjunatha (✉)
Division of Agricultural Structures and Environmental Control,
Central Institute of Post Harvest Engineering and Technology,
P.A.U. Campus,
Ludhiana, Punjab, India 141004
e-mail: manjanphd_8963@rediffmail.com

atmosphere (CA), storage should not exceed 2 weeks (Buescher 1987). Saltveit 2001; Salunkhe and Desai (1984) recommended storage period of 2–3 weeks and CA with 3–5 % CO₂ + 3–5 % O₂.

Modified atmosphere packaging (MAP) of vegetable combined with cold storage is considered as the best way to prolong the shelf-life period (Sandhya 2010), maintain sensory and microbiological quality of fresh-cut produce (Kader et al. 1989; Philips 1996). MAP has been developed over the last decades as a technique to retain high quality of vegetables (Charles et al. 2008). MAP delays ripening and senescence, reduces respiration rate, ethylene production, texture loss, rate of microbial growth and spoilage, chlorophyll and other pigment degradation (Rodriguez-Aguilera and Oliveira 2009). For crops which are sensitive to chilling temperatures, the increase in humidity and the reduction in O₂ concentration and accumulation of CO₂ within the package often are beneficial for preventing the development of chilling injury symptoms (Forney and Lipton 1990). One of the major effects of packaging is the maintenance of high humidity surrounding the products. Increase in CO₂ and decrease in O₂ levels have been shown to reduce chilling injury of avocados, grapefruit, peaches, nectarines, okra, pineapples, potatoes, and zucchini squash (Wang 1993).

Sudhakar Rao et al. (2000) studied the effect of MAP and shrink wrapping on shelf life of cucumber at 10 °C. Individual shrink wrapping, a form of MAP, is used to enhance the storage life and to maintain the harvest freshness of fruits and vegetables (Dhall et al. 2010). Srilaong and Tatsumi (2003) studied the effects of controlled atmosphere (CA) at 5, 21 (air, control) and 100 % O₂ on chilling injury, respiratory and anti-oxidative parameters at 5, 10 and 20 °C in cucumber fruit. It was observed that the appearance of chilling injury symptoms in cucumber was delayed in both CA treatments. Wang and Qi (1997) reported that cucumbers packaged in perforated or sealed 31.75 µm low density polyethylene (LDPE) bags were found to have less severe chilling injury than non-wrapped fruit in storage at 5 °C and 90–95 % relative humidity (RH). It is not known if the CO₂ accumulated in the film package would adversely affect the sensitivity of cucumbers to chilling.

It is clear from the reported studies that cucumber could be stored for maximum 3 weeks even in CA storage with acceptable quality. Controlled atmosphere storage is costly and requires precise gas and temperature control. It is not clear from the reported results whether the cucumber should be stored at minimum 4 or 5 or 10 °C. The firmness, colour and size are important quality characters which affect the market price of cucumber. Additional quality indices are freedom from handling defects and decay (Dhall et al. 2010). In recent years, the use MAP for fruits and vegetables in retail stores and local markets and by local vendors has been increased by many folds. However, MAP is hardly

followed for cucumber despite many advantages. MAP for cucumber can be used by retail stores, local markets and vendors and even in individual household because it is simple, easy to use and inexpensive method. Very little work has been reported on MAP of cucumber to understand in detail the effect of in-pack atmosphere and different storage conditions on quality, chilling injury and sensory characteristics of cucumber. Therefore the present study was undertaken to investigate the effect of modified atmosphere packaging and storage conditions on quality characteristics of cucumber.

Materials and methods

Packaging and storage

Uniform size and immature green cucumbers (cv. Pusa Uday) were procured early in the morning from the farmer's field, Ludhiana district. Immediately, procured cucumbers were divided into two lots and one lot was kept inside a cold room (Sheel Biotech Ltd, India) at 4±1 °C whereas another lot was kept at ambient condition (23 °C). Manual sorting was done to separate misshapen, decayed, damaged, and defective cucumbers from healthy uniform size green cucumbers of both the lots at their respective storage conditions. Healthy uniform size green cucumbers were used for the study. The modified atmosphere (MA) was created using a perforated low density polyethylene (LDPE) film bags having 107 µm thickness and size of 0.075 m². The gas transmission rates of the packaging film for O₂ and CO₂ were measured by a gas permeability tester (Labthink, model BTY-B1P, China). The water vapour permeability of the packaging film was measured by a water vapour permeability tester (Labthink, model TSY-W3, China). Water vapour transmission rate (WVTR) was 0.725 g.m⁻² atm⁻¹ day⁻¹ (at 30 °C and 85 % RH) whereas gas permeability coefficients for O₂ and CO₂ were 2.04×10⁻⁶ and 15.34×10⁻⁶ ml.mm⁻²h⁻¹kPa⁻¹ (at 5 °C and 90 % RH). The packed cucumbers were stored under cold room condition (4±1 °C and 90±2 % RH): i) Unsealed (US + CR); ii) 2 perforations (2P + CR); iii) 4 perforations (4P + CR) and under ambient condition (23–26 °C and 63–66 % RH): I) Unsealed (US + AMB); II) 2 perforations (2P + AMB); III) 4 perforations (4P + AMB). Cucumber kept in the unsealed LDPE bags at both the conditions were taken as control samples. Three cucumber fruits were placed in each bag and three bags were removed at each sampling for analysis of quality, chilling injury and sensory characteristics.

Package headspace analysis

Package headspace was measured in sample packages by using a portable Gas Analyzer (Model 902D Dualtrak,

Quantek, USA). The instrument evaluated the headspace by means of an electrochemical and an infrared sensor (sensitivity: 0.1 % O₂; 0.1 % CO₂, accuracy: 0.1 % O₂; 0.2 % CO₂) for O₂ and CO₂ concentrations, respectively. The instrument was calibrated with the standard O₂ and CO₂ gases. The drawn samples were fed simultaneously to the O₂ and CO₂ sensors and concentrations of O₂ and CO₂ were directly read on the digital display panel of the instrument.

Firmness determination

The firmness of the cucumber was determined using texture analyzer (Model TAHDi make, stable Microsystems, UK). Compression probe (P-5) having 5 mm in diameter and test speed of 5 mm/s was used to measure firmness of the cucumber. The firmness was expressed in newton. Measurements were made at three locations (top, middle and bottom) of each sample with peel.

Weight loss

During storage period, the weight loss (WL, %) of the sample was calculated as per cent change in weight based on the initial and final weight using a laboratory level weighing scale having 0.01 g accuracy (Scaltec Instruments, Germany).

Colour evaluation

The color of cucumber was measured with the help of Hunter Lab Miniscan XE Plus colorimeter (Hunter Associates Laboratory Inc., Reston, VA, USA) (Hunter 1975). The color values of cucumber were expressed as Hunter color 'L' value ('100 L' and '0 L' indicate white and black), 'a' value ('-a' and '+a' values indicate greenness and redness) and 'b' value ('-b' and '+b' values indicate blue and yellow). For color determination of each sample, the reflectance spectra were measured at 3 different points on the sample surface and then the mean value was obtained.

Chilling injury and sensory quality evaluation

Chilling injury is a physiological disorder induced by low temperatures resulting in surface pitting, decay, sunken spots and scattered water soaked areas. These chilling injury symptoms become more pronounced and visible clearly under normal temperature. The severity of chilling injury was evaluated as per the method described by (Wang and Qi 1997). The severity of chilling injury was evaluated 24 h after cucumbers were transferred from refrigerated condition to room temperature in order to get proper and clear visual observation on chilling injury symptoms. The degree of chilling injury, as judged by the extent of surface pitting, was rated on a scale of 1–5, with 1, no abnormality; 2, trace;

3, slight; 4, moderate; and 5, severe chilling injury. Sensory evaluation of cucumbers consisted of preference rating for three sensory characters viz., appearance, flavour and texture by a 10 member trained panel using 9 point Hedonic scale (9 = excellent pleasant, 1 = very poor) for each of four sensory characters as per method described by Amerine et al. (1965). Decay percentage was measured in terms of extent of cucumber spoilage due to shrivelling and softening of fruit ends due to water loss, chilling injury and rotting due to appearance of disease was recorded and the cumulative fruit decay percent was worked out.

Statistical analysis

The statistical analysis of data obtained was carried out to analyze the differences among the treatments during storage period. All the experiments were performed in triplicate. Two-way analysis of variance (ANOVA) and the significant difference of the data at $p < 0.01$ was carried out using a statistical package (AgriStat, IASRI, New Delhi) and the means were plotted to draw out inferences.

Results and discussion

Package headspace composition

Package headspace compositions of O₂ and CO₂ under packaging treatments (2 and 4 perforations) at cold room and ambient conditions are plotted in Fig. 1a. During initial 4 days of storage, a rapid decrease in O₂ and a corresponding increase in CO₂ concentrations were observed which could be due to high respiration rate of cucumbers in the transient state of stabilisation and equilibration. The O₂ concentration inside the 2P + CR, 4P + CR, 2P + AMB and 4P + AMB package treatments reached to 15.9, 17.3, 12.4 and 16.3 % on the 4th day of storage and corresponding CO₂ concentration recorded to be 5.4, 4.0, 9.1 and 3.9 %, respectively. After 4 days, the respiration rate of cucumbers decreased suddenly which resulted in-pack accumulation of O₂ under all the treatments with more accumulation of O₂ in the packages having 4 perforations as compared to the packages having 2 perforations in which there was no much change of in-pack gas concentration. In the case of packages containing 2 perforations stored at both the storage conditions, the in-pack gas concentration was well adjusted as compared to the packages having 4 perforations which may be due to more perforation area of the packages having 4 perforations.

Firmness

The Fig. 1b shows the firmness results of cucumber under MAP and unsealed packages stored at cold room and

Fig. 1 (a and b): In-pack gas concentrations (a) and firmness (b) of cucumber stored under perforated MAP at CR (4 ± 1 °C and 90 ± 2 % RH) and AMB conditions ($23\text{--}26$ °C and $63\text{--}66$ % RH) ($n=3$); 2P and 4P are 2 and 4 perforations; AMB ambient, CR cold room, US unsealed, N newton

ambient conditions. The results revealed that the firmness of cucumbers was found to be decreased significantly at 99 % confidence level with p -value <0.01 (Table 1) during initial 6 days of storage period and same trend was observed except in the treatments US + AMB and 4P + AMB in which it was observed to be increased in firmness after 6 days of storage due to shrivelling of cucumber peel on loss of more moisture which experienced more compression force. It is clear from the Fig. 1b that the cucumber stored under unsealed pack at cold room condition registered maximum loss of firmness (from 0.38 to 0.33 N) which could be due to chilling injury which caused softness on thawing after taken out from cold room. The least change in firmness was observed with the treatment 2P + CR could be due to better adjustment of in-pack atmosphere combined with

high relative humidity which reduced the loss of moisture from the cucumber.

Weight loss

Weight loss (WL, %) of cucumber under MAP and unsealed packages stored at cold room and ambient conditions is shown in Fig. 2c. The WL was significantly minimum in all the packaging treatments stored at cold room condition as compared to packaging treatments stored at ambient condition. The WL was in the range of 0.98 to 7.54 % and 1.62 to 12.89 % after 6 and 12 days of storage, respectively. After 12 days of storage the highest WL (12.89 %) was recorded in unsealed sample stored at ambient condition which could be attributed to high respiration rate (Dhall et al. 2010; Wang and Qi 1997) whereas cucumber stored under MAP with 2 perforations at cold room condition registered the lowest WL (1.62 %) due to the effect of low temperature and better adjustment of in-pack headspace and relative humidity which is in conformation with the earlier reported results of Tomkins and Cumming (1988); Among all the packaging treatments, storage period and interaction of treatments and storage period, the decrease in WL was statistically significant at 99 % confidence level with p -value <0.01 which indicated a major change in WL during storage (Table 1).

Colour

Besides firmness, colour is one the most important quality parameters of consumer acceptance. The Hunter colour 'L', 'a' and 'b' values of cucumber were measured before (on zero day) and after storage (on 12th day) to investigate the effect of perforated modified atmosphere packaging and storage conditions on extent of colour change and the colour values plotted in Fig. 2d–f. Among all the packaging treatments, storage period and interaction of treatments and storage period, the change in 'L' 'a' and 'b' values was statistically significant at 99 % confidence level with p -value <0.01 (Table 1). The 'L' values (whiteness) increased with storage period in all the treatments except in the treatment US + CR (Fig. 2d). The decrease in 'L' value in the cucumber kept unsealed under cold room condition (US + CR) could be due to appearance of small surface pits on 5th day then these pits were enlarged to large sunken spots and water soaked areas. The increase in 'L' values was minimum in the case of 4P + CR (40.6) and 2P + CR (36.93) from the initial 'L' values of 37.02 and 33.08, respectively. The increase in 'L' values was maximum in all the packaging treatments stored at ambient condition due to the effect of more light and enhanced respiration under high temperature which caused cucumber to turn whiteness from natural green colour. Hunter colour 'a' values (greenness) of cucumber stored at both the conditions were decreased

Table 1 ANOVA indicating the effect of macro perforated modified atmosphere packaging and storage conditions on firmness, colour, chilling injury and sensory characteristics of cucumber ($n=3$)

Parameter	Treatment (a)				Storage (b)				a×b (Interaction)			
	DF	MS	S/NS	CD	DF	MS	S/NS	CD	DF	MS	S/NS	CD
FMS	5	0.001	S	0.005	2	0.005	S	0.003	10	0.006	S	0.018
WL	5	45	S	0.42	2	90	S	0.026	10	14	S	0.06
L	5	132	S	0.02	1	371	S	0.01	5	381	S	0.02
a	5	1.9	S	0.03	1	36	S	0.02	5	4.6	S	0.05
b	5	85	S	0.32	1	0.04	S	0.18	5	62.35	S	0.45
CI	5	18	S	0.3	1	24	S	0.17	5	5.2	S	0.42
OSQ	5	54	S	0.53	1	118	S	0.3	5	4.2	S	0.75

DF degree of freedom, MS mean sums of squares, S significance, NS non-significance, CD critical difference ($p \leq 0.01$), WL weight loss, OSQ overall sensory quality, L 'L' value, a 'a' value, CI chilling injury, FMS firmness

(Fig. 2e). The change in 'a' values however was minimum in the samples stored at cold room condition. The least change in 'a' values (from -9.26 to -9.12) was observed in US + CR whereas US + AMB treatment registered

highest (from -9.88 to -5.47). The Fig. 2f indicates the there was increase in the yellowness values (b values) in the cucumbers stored at ambient condition whereas slight decrease in yellowness values was observed in the samples

Fig. 2 c–h Changes in quality characteristics of cucumber stored under perforated MAP at CR (4 ± 1 °C and 90 ± 2 % RH) and AMB conditions (23 – 26 °C and 63 – 66 %RH) ($n=3$); 2P and 4P are 2 and 4 perforations; AMB ambient, CR cold room, US unsealed

stored at cold room condition which could be due to better adjustment of in-pack atmosphere, low temperature and minimum effect of light inside cold room. The increase in yellowness values was more (from 25.87 to 35.82) in the unsealed sample stored at ambient condition whereas unsealed sample stored at cold room condition recorded lowest 'b' value (from 24.80 to 16.50) may be due to minimum effect of light inside cold room and low temperature. It was observed that least change in 'b' values in 2P + CR followed by 4P + CR.

Chilling injury and sensory quality evaluation

Results of chilling injury and sensory quality (appearance, texture and flavour) of cucumber stored under perforated MAP at cold room and ambient conditions are plotted in the Fig. 2g and h. On 12th day, the chilling injury (4.4 chilling injury score) was severe in unsealed sample and slight to moderate chilling injury was observed in 2 and 4 perforated package samples stored under cold room condition whereas chilling injury was not observed in all the samples stored at ambient condition. At the end of 6 days of storage, the treatments viz., 2P + CR, 4P + CR, 2P + AMB and 4P + AMB scored 8.2, 7.7, 7.1 and 6.8, respectively. The treatments US + AMB and US + CR scored less than 6 and were not in marketable condition even on 6th day of storage. On 12th day of storage, only two treatments i.e. 2P + CR and 4P + CR had scored slightly more than 7 and they were acceptable in condition. Among all the packaging treatments and storage period and their interaction, the change in sensory quality and chilling injury values was statistically significant at 99 % confidence level with p -value < 0.01 (Table 1). All the samples were not in acceptable condition on 15th day of storage as they registered sensory quality score less than 5.0 (data not shown) due to severe yellowing, shriveling, decay and off-flavour in case of samples stored at ambient condition whereas moderate off-flavour and severe chilling injury was observed in case of samples stored at cold room condition. The results were in agreement with the results reported by Dhall et al. (2010) and Sudhakar Rao et al. (2000).

Conclusion

Modified atmosphere packaging (MAP) having 2 perforations (0.33 mm dia each) combined with cold room condition (4 ± 1 °C and 90 ± 2 % RH) had maintained good in-pack modified atmosphere and found to be beneficial effect on firmness, fruit weight, colour and sensory characteristics of cucumber with reduced chilling injury. Cucumber can be stored under MAP with 2 perforations at low temperature (4 ± 1 °C and 90 ± 2 % RH) and ambient condition (23 – 26 °C and 63 – 66 % RH) for 12 and 6 days, respectively.

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