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ORIGINAL ARTICLE

Enhancing shelf life of minimally processed multiplier onion using silicone membrane

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Abstract The aim of storage of minimal processed product is to increase the shelf life and thereby extend the period of availability of minimally processed produce. The silicone membrane makes use of the ability of polymer to permit selective passage of gases at different rates according to their physical and chemical properties. Here, the product stored maintains its own atmosphere by the combined effects of respiration process of the commodity and the diffusion rate through the membrane. A study was undertaken to enhance the shelf life of minimally processed multiplier onion with silicone membrane. The respiration activity was recorded at a temperature of 30±2 °C (RH= 60 %) and 5±1 °C (RH=90 %). The respiration was found to be 23.4, 15.6, 10 mg $CO_2 kg^{-1} h^{-1}$ at 5±1 °C and 140, 110, 60 mg $CO_2 kg^{-1} h^{-1}$ at 30±2° for the peeled, sliced and diced multiplier onion, respectively. The respiration rate for the fresh multiplier onion was recorded to be 5, 10 mg $CO_2 kg^{-1} h^{-1}$ at 5±1 °C and 30±1 ° C, respectively. Based on the shelf life studies and on the sensory evaluation, it was found that only the peeled multiplier onion could be stored. The sliced and diced multiplier onion did not have the required shelf life. The shelf life of the multiplier onion in the peel form could be increased from 4–5 days to 14 days by using the combined effect of silicone membrane (6 cm^2/kg) and low temperature (5±1 °C).

Keywords Controlled atmosphere · Low temperature · Modified atmosphere · Shelf- life · Silicone membrane · Multiplier onion

Ready to use vegetables are increasingly favoured by the consumers who look for the healthy food that requires little preparation. “Minimally processed” horticultural products are prepared and handled to maintain their fresh nature while providing convenience to the user. Producing minimally processed products involves cleaning, washing, trimming, coring, slicing, shredding, and so on. Other terms refer to minimally processed products are “lightly processed,” “partially processed,” “fresh processed,” and “preprepared.”

Multiplier onion *(Onion aggregatum)* is consumed in large quantity in the southern provinces of India. Peeling is a time consuming process, as a result of which the working women do not prefer using this particular type of onion even though it is much preferred and reported to have many medicinal advantages. These are used in large quantity in the catering and pickling industries creating a need for the peeling and minimal processing technology. Presently processing of onions is as dried, pickled or powdered products, but their use as peeled ready to use vegetables has been little studied.

Low temperature with regular atmosphere (RA), low temperature with regular atmosphere and high RH atmosphere (HRA) and low temperature with high RH and modified/controlled atmosphere (MA/CA) storage are the common methods used to maintain the quality of freshly harvested produce. Modified atmosphere storage is one of the methods for extending shelf-life of the perishable and semi-perishable products by altering the relative proportion

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of atmospheric gases that surround the product (Day 1992). Proper control of temperature, RH and storage gas composition can maintain the product quality for longer periods than refrigeration and high RH alone (Raghavan and Gairepy 1984).

Silicone membrane technique is a controlled ventilation system that regulates gas levels of storage environment by relying on selective gas permeation (Raghavan et al. 1982; Gariepy et al. 1984). The membrane makes use of the ability of polymer to permit selective passage of gases at different rates according to their physical and chemical properties. The membrane is characterized by its gas diffusion rate and its selectivity. It is the gas permeability of membrane combined with respiratory activity of product that permits enrichment of CO_2 and depletion of O_2 inside the storage unit. The main advantages of silicone membrane system are

i. Lower operating cost due to fewer controls and less maintenance during operation.
ii. Lower refrigeration cost attributable to lower respiratory activity
iii. The membrane's high permeability to ethylene
iv. Low permeability to water vapour

Materials and methods

Preparation of multiplier onion for the experiments

Pungent Multiplier onion (Co-3) were taken from the famers field grown under the technical guidance of the Central Institute of Agricultural Engineering, Regional centre Coimbatore. The multiplier onions were graded to remove the damaged/spoiled fruits and the uniform size fruits were used for the storage studies. Preparation of the material was carried out at low temperature. The onions were peeled, sliced (2 mm thickness) and diced (1 × 1 cm) manually with a sharp knife with minimal damage. The onion peeled, sliced and diced was subdivided into samples of 400 g, dipped in cold water for 1 min, and excess moisture was removed with a household spin-dryer.

Physiological loss in weight (PLW)

Samples were weighed during storage at regular intervals with the help of an electronic balance having a least count of 0.01 g.

Silicone membrane and its gas permeable properties

Silicone rubbers belong to the class of substance termed 'polymers' which are characterized by high molecular weight compounds with long molecules made of repeating units. Silicone rubbers are unique among the many types of natural and synthetic rubbers available in the sense that instead of the usual chain of carbon atoms, the "backbone" of their molecules is made of alternate atoms of silicones (Si) and oxygen (O_2). Various organic side groups can be attached to the chain to modify the characteristics. In dimethyl silicone rubber, the organic side groups are CH_3.

Silicone rubbers have extremely good thermal stability, excellent electric insulating properties, outstanding water repellency, good chemical resistance but very weak strength and often need to be reinforced. For coating purpose, dimethyl polysiloxane, a highly viscous liquid is used (Ash and Ash 1983; Roff *et al.* 1971, Naik and Kailappan 2007). The silicone membrane is available commercially in 1.54 m wide rolls of various lengths.

The gas exchange with the atmosphere surrounding the packaged material using silicone takes place due to various properties of the membrane. The main characteristic to consider when selecting packaging materials for MAP of fruits and vegetables is gas permeability. Under steady state conditions, the gas transmission rate through the membrane is taken along with temperature and membrane thickness (ASTM 1978).

Respiration rate measurement

Various forms of minimally processed multiplier onion viz., peeled, diced and sliced were used to find out the rate of respiration at ambient temperature (30±2 °C; 60 % RH) and also at low temperature (5±1 °C; 90 % RH). Each O_2 depletion run was performed to measure the respiration rate with 0.2 kg of multiplier onion held in the respirometer containing one normal KOH as a CO_2 absorbent. A stainless steel cup of about 2 cm height was used in the respirometer to separate the chemicals at the bottom and the products above it, as done by Jurin and Kader (1963) and Henig and Gillbert (1975). Samples used in all these experiments were approximately of same size. Gas samples were drawn and analysed for O_2 concentration at every 1 h interval for ambient temperature and 2 h interval for low temperature. Each O_2 depletion experiment was carried out till O_2 concentration reached nearer to zero per cent. The experiment was replicated thrice.

Development of respirometer

A unit (respirometer) (Fig. 1) to measure the respiratory activities of the multiplier onion was fabricated. It is an air tight container with a gas inlet, outlet and a port for gas sampling. It consisted of a glass jar resting on a flat mild steel plate and a cover made of another plate. The joint between the glass jar and the top cover plate was made airtight by providing a neoprene rubber gasket. The top

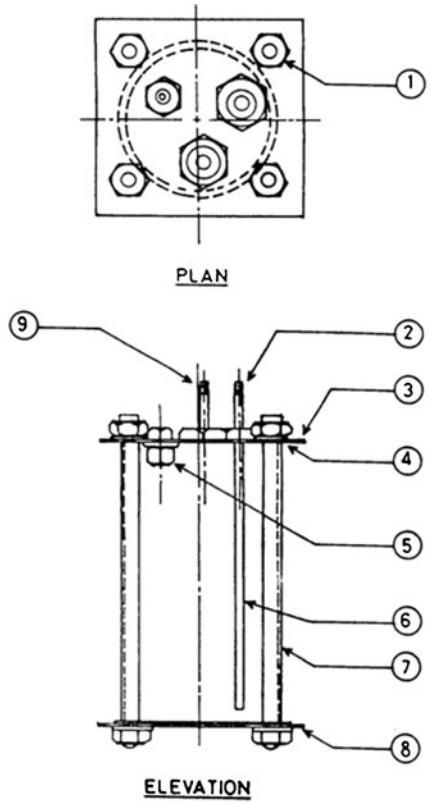

Fig. 1 Respirometer

cover had three holes each for providing the silicone rubber septum for gas sampling, plastic tube extended to the bottom as a gas inlet and a gas outlet. The gas entering through the long plastic tube (gas inlet) spread out axially and moved upwards through the multiplier onion, thus flushing out the existing gas in the respirometer. Gas tightness of the respirometer was verified. This was used in the respiration test of the minimally processed multiplier onion.

Gas analysis

Gas analysis was done using gas chromatography. Nitrogen, Oxygen and Carbon-di-Oxide concentrations were determined with thermal conductivity detector (TCD), molecular sieve column (diameter 2 mm and length 2,000 mm), Poropak - Q columns (diameter 2 mm and length 2,000 mm) and hydrogen as the carrier gas. Ethylene was detected using flame ionization detector (FID), Poropak - Q column using Nitrogen as carrier gas and hydrogen as fuel. In both the cases, gas flow rate was 30 ml/min.

Storage studies

The objectives of this work were to develop and evaluate laboratory scale modified atmosphere storage units, corresponding to the design criteria. Firstly the laboratory scale MA units of 1 kg capacity were developed and its performance was evaluated.

The main design criteria for a stable gas concentration during storage are proper selection of membrane and its windows area. Procedure to calculate the membrane area required is based on the level of CO_2 desired in the storage chamber. The basic equation for calculation of membrane area as described in Raghavan *et al.* (1982) and summarised by the following equation was used

$$Area = \left[\frac{(RR * M)}{(P_{CO_2} * CO_2)}\right]$$

Area Silicone membrane area (m^2)

RR Respiration rate of the product stored under MA condition (L of CO_2 kg^{-1} day^{-1})

M Mass of stored produce (kg)

P_{CO2} Permeability of the silicone membrane to CO_2 ($L\,day^{-1}\,m^{-2}$ Atm^{-1}), and

CO_2 Desired CO_2 Partial pressure difference across the membrane (Atm)

Polyethylene Tetra Phthalate (PET) containers of 1,000 ml capacity were used for the storage studies. The lids of the bottles were cut open to different areas to place the silicone membrane of different surface areas to maintain the desired CO_2 concentrations as described by equation. The openings were made according to the equation and covered with the silicone membrane to maintain the concentrations of CO_2 to 2, 4, 6 and 8 % inside different MA units. Araldite epoxy resin gum was used for pasting the membrane over the cut openings of MA units. Gas sampling septums are provided at both bottom and top of the MA Unit in diametrically opposite fashion.

Measurement of design parameters

The MA units developed were evaluated for multiplier onion, at two levels of temperature (30±2 °C; 60 % RH and 5±1 °C; 90 % RH) at different gas concentrations

Lab scale storage of minimally processed multiplier onion

The minimally processed multiplier onion were stored in two different storage conditions viz., at room temperature and in low temperature of 5±1 °C. The temperature and RH data were recorded for the ambient storage during the period of experiment.

Storage of multiplier onion at ambient condition

One kg of minimally processed multiplier onion was selected at random for each treatment. All treatments were kept in ambient condition at about 30±2 °C. During the storage period, the temperature varied from 28.5 °C to 32 °C and the relative humidity varied from a minimum of 78 % to a maximum of 90 %.

Storage under regular atmosphere (Control, TA_o)

The minimally processed multiplier onion was kept in plastic tray and three replicates were taken for the evaluation of their quality parameters.

MA storage using Silicone membrane

The MA units with silicone membranes were developed as discussed above. The basic equation was used for the determination of membrane area and respiration rate at ambient temperature was used for the calculation. Minimally processed multiplier onion fruits weighing approximately 0.5 kg were stored in the MA units. After securing the lid tightly, the lid joint was covered with a gum tape. Three replications of each treatment (2, 4, 6 8 and 10 % CO_2) were taken out for the estimation of quality parameters. The gas compositions (mainly CO_2 and O_2) were analysed using gas chromatographs with the same intervals. The details of membrane treatments are as follows

a) Two per cent carbon dioxide (TA_2)
b) Four per cent carbon dioxide (TA_4)
c) Six per cent carbon dioxide (TA_6)
d) Eight per cent carbon dioxide (TA_8)
e) Ten per cent carbon dioxide (TA_{10})

Storage of minimally processed multiplier onion at low temperature

The pre treated minimally processed multiplier onion were stored in low temperature in the same way as in the case of ambient storage. The storage temperature was maintained at a rage of 5 ± 1 °C and 85–90 % RH. Details of the treatments given in the low temperature conditions are given below

Regular atmosphere

Here the minimally processed multiplier onions were kept in plastic trays and stored products were evaluated for their quality parameters. This treatment is denoted as TC_0 (Control)

MA storage using silicone membrane

The treatments were laid out in a similar way as that of ambient storage. For the determination of membrane area, Respiration rate of minimally processed multiplier onions at 5 ± 1 °C was used. Various treatments used under silicone membrane are as follows:

a) Two per cent carbon dioxide (TC_2)
b) Four per cent carbon dioxide (TC_4)
c) Six per cent carbon dioxide (TC_6)
d) Eight per cent carbon dioxide (TC_8)
e) Ten per cent carbon dioxide (TA_{10})

Measurement of onion flavor

A common assessment of pungency is made by measuring pyruvate, which is formed as a stable primary compound from the enzymatic decomposition of each of the flavor precursors. Pyruvate is produced in a mole for mole relationship with the flavor precursors. It is, however, only an indicator of pungency as pyruvate does not directly contribute to onion flavor.

Pyruvic acid was determined on samples of 30 g tissue, using the method of Schwimmer and Weston (1961). Control samples, in which alliinase was inactivated by microwave heat treatment for 2 min at maximum intensity, were prepared under the same conditions as the raw samples. Absorbance was determined spectrophotometrically at 440 nm using a standard curve of pyruvic acid. The pyruvate content is related to the flavor index. This was calculated as the difference between the total value of the sample and that of the control. Results are expressed as µmol pyruvic acid per g fresh tissue.

Visual score

During the storage, visual quality according to general appearance of minimally processed multiplier onion held under the different storage conditions was assessed using 9 point hedonic scale. The overall rating was calculated by averaging the score. Samples which obtained a score of 5.5 and above were considered as acceptable. (Bruno et al. 2006; Sukalakamala and Brittin 2006; Phongsomboom and Pilairuk 2009).

Statistical analysis

All the experiments were performed three times. Data was analysed by one way analysis of variance (ANOVA) at 5 % level to test the significance among values of shelf life. SPSS package and curve fit 7.0 software were also used.

Results and discussion

Respiration studies

To optimize the storage conditions using the silicone membrane, it is necessary to study the respiratory activity of the multiplier onion. In this regard, the respiration rate was measured for multiplier onions for sliced (2 mm thickness), diced (1×1 cm), peeled onions and fresh onions. The time taken in hours for the oxygen concentration to deplete to 15, 10, 5 and 2 % from the initial concentration of 21.03 % was recorded and based on this the rate of oxygen depletion was measured. The samples viz., peeled, diced and sliced multiplier onions were placed in the respirometer. The gas samples was drawn and analysed for oxygen concentration at one hour interval for samples stored at 30±2 ° C and every 2 h for the samples stored at 5±1 °C. The time taken for depletion of oxygen from 21.03 % to about 2 % was about 10.2 h, 5 h and 3.1 h for peeled, diced and sliced multiplier onion, respectively at ambient temperature (Fig. 2). Whereas the time taken for depletion of oxygen from 21.03 % to about 2 % was about 72 h, 53 h and 30 h for peeled, diced and sliced multiplier onion, respectively at low temperature (Fig. 2). The respiration was found to be 23.4, 15.6, 10 mg $CO_2 kg^{-1} h^{-1}$ at 5±1 °C and 140, 110, 60 mg $CO_2 kg^{-1} h^{-1}$ at 30±2 °C for the peeled, sliced and diced multiplier onion, respectively. The respiration rate for the fresh multiplier onion was recorded to be 5, 10 mg $CO_2 kg^{-1} h^{-1}$ at 5±1 °C and 30±2 °C, respectively. Based on the respiration rate, the surface area of the silicone membrane required to maintain the modified atmosphere condition to store 0.5 kg of the product was worked out.

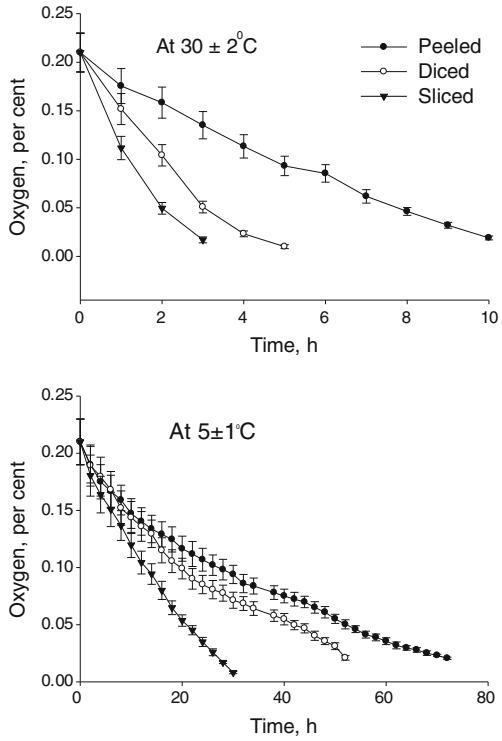

Fig. 2 Oxygen depletion values of minimally processed multiplier onions at 30±2 °C and 5±1 ° C (n=5)

Optimization of silicone membrane area for storage studies

Based on the respiration rate, the surface area of the silicone membrane required to maintain the modified atmosphere condition to store 0.5 kg of the product was worked out. . But while actual measurement of the gases, achieved gas level (CO_2) are different from the desired gas levels. Therefore a new design equation for the calculation of membrane area was developed from the achieved gas concentrations. The equations were obtained using SPSS package for the membrane area by considering both CO_2 and O_2. The calculation of the area of silicone membrane required for various levels of CO_2 (2, 4, 6, 8 and 10 %) were made as per the new equation obtained by means of software "Curve fit" version 7.1. It is seen that as the required CO_2% in the MA units increases, the surface area of the silicone membrane decreases. This is due to the fact that surface area is inversely related to the desired CO_2 concentration in the chamber (Raghavan et al. 1982). The relationship is in the exponential form in the new equation obtained,

Relation between $A_1$and $A_2$is : $A_2 = a(A_1)^b$

Where; A_1 is the Silicone membrane area in cm^2 according to Raghavan et al. (1982). A_2 is the silicone membrane area in cm^2 according to the present study. The value of constants "a" and "b" differs with various types of minimally processed product and is given in Table 1. It is seen that the r^2 values of modified equation is very good (0.999). Based on the modified equation the silicone membrane window was worked out and the shelf life studies carried out.

Shelf life of minimally processed multiplier onion

The recording the details of the shelf life of minimally processed multiplier onion in various forms like peeled, diced and sliced using silicone membrane storage system at ambient and low temperature, it is observed that the shelf life of sliced and diced onion was very low (less than 1 day) at ambient temperature (30±2 °C; 60 % RH) . Whereas at low temperature storage (5±1 °C; 90 % RH) it ranged from 2–3 days. In view of this, diced and sliced minimally processed onion was not taken for shelf life study as they did not have sufficient shelf life. Only the peeled multiplier onion was considered for shelf life studies. The shelf life of the peeled onion was recorded as 3 and 14 days at ambient and low temperature, respectively at 6 % CO_2 level

Table 1 Values of constants "a" and "b" for modified equation to calculate the silicone membrane area

Parameters	Ambient			Low temperature		
	Sliced	Diced	Peeled	Sliced	Diced	Peeled
r^2	0.999	0.999	0.999	0.999	0.999	0.999
a	0.00184	0.00476	0.00019	0.00185	0.00217	0.00449
b	23.53	22.72	21.35	8.88	9.01	7.52

and it reduced when the CO_2 level was either increased or reduced by manipulating the silicone membrane area.

Effect of modified atmospheric storage on the pungency of Multiplier onion

The analysis of pungency of the stored minimally processed onion revealed that the pungency reduced with the time of storage. However the reduction was within the accepted limits of 14 μ mol pyruvic acid (Schwimmer and Weston 1961). The modified atmosphere storage condition reduced the rate of reduction in pungency during storage. The pungency level was recorded to be about 16.9 μ mol pyruvic acid for the freshly peeled multiplier onion. This reduced to 14 μ mol pyruvic acid at the end of storage period of 14 days using silicone membrane and targeted $C0_2$ of 6 %.

Sensory evaluation of Peeled Multiplier onion

The ultimate quality assessment of modified atmosphere stored multiplier onion should satisfy the requirements of the consumers. If the colour, flavour, texture and overall acceptance are comparable to those of fresh product then they may be considered as having a good market value. The panel of 14 untrained members was requested to assess the quality of peeled multiplier onion. Mean score of test panel analysed is presented in Table 2.

Table 2 Changes in sensory quality of fresh and modified atmosphere stored peeled multiplier onion during storage at 30±2 °C and 5±1 °C

Treatment	Days of storage									
	2	3	4	5	6	8	10	12	14	16
Colour										
Fresh(LT)	7.3±0.23^b	7.0±0.19^c	6.5±0.16^a	6.0±0.14^a	N.A	N.A	N.A	N.A	N.A	N.A
MAS	7.0±0.22^a	6.1±0.16^a	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A
MAS (LT)	8.4±0.24^c	6.9±0.18^b	7.1±0.19 ^{b}	7.0±0.18^b	6.9±0.15	6.4±0.16	6.0±0.15	5.8±0.16	5.6±0.09	N.A
CD(0.05)	0.45	0.36	0.23	0.31	–	–	–	–	–	–
Flavour										
Fresh(LT)	7.3±0.17^b	6.9±0.17^b	6.1±0.11 ^{a}	5.9±0.09 ^{a}	N.A	N.A	N.A	N.A	N.A	N.A
MAS	6.3±0.13^a	6.0±0.13 ^{a}	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A
MAS (LT)	8.1±0.21^c	7.9±0.19^c	7.5±0.18 ^{b}	7.2±0.14^b	7.1±0.12	6.9±0.11	6.5±0.11	6.0±0.10	5.8±0.09	N.A
CD(0.05)	0.39	0.31	0.41	0.38	–	–	–	–	–	–
Texture										
Fresh(LT)	7.9±0.19^b	6.7±0.17^b	6.5±0.15 ^{a}	6.1±0.10^a	N.A	N.A	N.A	N.A	N.A	N.A
MAS	6.5±0.16^a	6.2±0.12 ^{a}	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A
MAS (LT)	8.2±0.25^c	8.0±0.23 ^{c}	7.5±0.21^b	7.3±0.21^b	7.2±0.19	7.0±0.19	6.7±0.17	6.4±0.15	6.1±0.11	N.A
CD(0.05)	0.33	0.31	0.27	0.25	–	–	–	–	–	–
Overall acceptance										
Fresh(LT)	7.9±0.20^b	7.0±0.17^b	6.5±0.13^a	6.2±0.12^a	N.A	N.A	N.A	N.A	N.A	N.A
MAS	6.5±0.16^a	6.3±0.15^a	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A
MAS (LT)	8.4±0.25^c	8.1±0.21^c	7.5±0.18^b	7.2±0.16^b	7.2±0.16	6.9±0.14	6.6±0.13	6.2±0.11	5.9±0.11	N.A
CD(0.05)	0.35	0.37	0.24	0.21	–	–	–	–	–	

Each observation is a mean±CD (n=5); Number of panelist – 14

All fresh samples stored at ambient temperature (30±2 °C) were not acceptable

LT Low temperature (5±1 °C); *MAS* Modified atmosphere storage; *N.A* Not Acceptable

The mean score of 5.5 and below was recorded as unacceptable. From this table it is seen that the shelf life of the peeled multiplier onion at ambient condition is less than 2 days; where a peeled multiplier onion stored in combination of silicone membrane and ambient condition is less than 4 days (say 3 days). Whereas in the low temperature, the multiplier onion in peeled form can be stored for about 5 days. The combination of low temperature and modified atmosphere storage gave the best shelf life of about 14 days.

Conclusion

Multiplier onion *(Onion aggregatum)* is consumed in large quantity in southern province of India. Peeling is a time consuming process, as a result of which the working women avoid this particular type of onion even though it is much preferred and reported to have many medicinal advantages. These onions are used in large quantity in the catering and pickling industries creating a need for peeling equipment. An attempt was made to study the respiratory activities of the minimally processed multiplier onion in various forms viz., peeled, sliced and diced multiplier onion. The respiration was found to be 23.4, 15.6, 10 mg $CO_2 kg^{-1} h^{-1}$ at 5±1 °C (RH=90 %) and 140, 110, 60 mg $CO_2 kg^{-1} h^{-1}$ at 30±2 °C (RH=60 %) for the peeled, sliced and diced multiplier onion, respectively. The respiration rate for the fresh multiplier onion was recorded to be 5, 10 mg $CO_2 kg^{-1} h^{-1}$ at 5±1 °C and 30± 2 °C, respectively. The time taken for depletion of oxygen from the ambient concentration of 21 % to about 15, 10, 5 and 2 % were analysed for peeled, diced and sliced onion aggregatum at 5±1 °C and 30±2 ° C temperatures so that the optimum storage conditions could be worked out with respect to various packaging medium. Based on the shelf life studies and on the sensory evaluation, it was found that only the peeled multiplier onion would be stored. The sliced and diced multiplier onion did not have the required shelf life, so the storage studies were carried out for the peeled multiplier onion. The shelf life of the multiplier onion in the peel form could be increased from 4–5 days in low temperature (5±1 °C) to 14 days by using the combined action of silicone membrane and low temperature storage. The pungency of the stored multiplier onion sample reduced with the time of storage, but the rate of reduction was within the acceptable limits. Hence this technology can be used to increase the shelf-life of minimally processed multiplier onion.

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