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Effect of modified atmosphere packaging on physical, bio-chemical and functional properties of Jamun (*Syzygium cumini*) during storage

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Modified atmosphere packaging (MAP) of jamun (*Syzygium cumini*) was studied in macro-perforated (4, 8 and 12 perforations, 0.03 mm dia. each) polypropylene (PP) film (thickness: 50 µm, dimension: 30x10 cm) and extended polystyrene trays with cling package (thickness: 20-micron, width: 20 cm) at different storage conditions i.e., cold storage at temperature 1-3°C, 90% RH, refrigerated storage at 8-10ºC, 80-85% RH and ambient temperature 25-28ºC, 70-80% RH. Changes in different physical, biochemical parameters i.e., headspace gas composition %O_2 & CO_2, physiological weight loss %, colour, anthocyanin content, ascorbic acid content, total soluble solids and titratable acidity were determined at every 7 days intervals up to 30 days. The headspace gas concentration in 4 perforations PP at refrigerated storage (8-10ºC, 80-85% RH) was observed to be: CO_2 = 4.55% and O_2 = 17.45%, whereas, CO_2 = 2.7% and O_2 = 16.67% in case of cold storage after 30 days storage. Physiological weight loss of samples was minimum and the purplish-blue colour, ascorbic acid content, was retained maximum in 4 perforations PP cold storage samples. Anthocyanin content was retained maximum (92.8%) in 8 perforations cold storage sample. Total microbial load was minimum ($1.39x10^4$ cfu/g) in case of 4P PP samples in cold storage. Sensory analysis of MAP of jamun suggested that the overall acceptability score > 7.08±0.16 were obtained, in terms of taste and colour and found suitable for consumption even after 30 days of storage.

Keywords: Anthocyanin content, Ascorbic acid content, Jamun, Modified atmospheric packaging, Overhead gas composition, Physiological loss in weight, Shelf life, Total phenolic content

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Indian blackberry, *Jamun* (*Syzygium cumini*) is commonly grown as a non-timber forest produce consumed as fresh fruit, juice, RTS or nectar. World production of Jamun is estimated at 13.5 million tonnes and 15.4% is contributed by India, which ranks second in production of Jamun in the world[1]. The Jamun fruit has a great potential as an alternative medicine to treat various diseases. It is rich in phytochemicals like glycoside jambolin, anthocyanins, tannins, terpenoids, gallic acid and various minerals[2]. This wide range of health promoting compounds makes it popular to be used as nutraceutical. The fruits are purplish black in colour when ripe and it contains high amount of anthocyanins[3].

Jamun is a highly perishable fruit, only available in one season from April to July in temperate climate. It decays within 2 days in ambient conditions, requires proper storage and packaging conditions to make it available throughout the year as well as make use of such a medicinal fruit in raw form. There are several researches have been reported and products have been developed from jamun pulp, dried jamun, jamun fermented product or seed powder but fresh jamun fruit as a whole for raw consumption after a long-term storage has not been studied yet[4,5].

Modified Atmospheric Packaging (MAP) concept consists of modifying the atmosphere surrounding a food product by passive, vacuum, gas flushing or controlled permeability of the pack thus controlling the biochemical, enzymatic and microbial actions so as to avoid or decrease the main degradations that might occur. It is a dynamic process during which respiration and permeation occur simultaneously. Factors affecting mainly commodity mass, temperature, O_2, CO_2 and partial pressures. Stage of maturity is known to influence respiration in a package[6]. The modified atmosphere packaging allows the preservation of the fresh state of the food product without the temperature or chemical treatments used by other preservation techniques, such as canning, freezing, dehydration etc.

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Fresh produce is more susceptible to disease organisms because of increase in the respiration rate after harvesting. There are many advantages of MAP fruit and vegetables, but the most obvious one must be the extension of shelf-life. By decreasing the amount of available oxygen to the produce, the respiration rate and the rate of all metabolic processes are correspondingly decreased. This results in delayed ripening and senescence, which may be seen as more anthocyanin and ascorbic acid retention, delayed softening and the preservation of a good quality fresh colour. Applications of MAP using suitably permeable or micro-perforated plastic films, which can extend shelf life without adversely affecting the eating quality, are illustrated by recent studies on tomatoes, peppers, mushroom, apples, foxtail millets, celery and pitaya fruits etc.[7-17]. The modified atmospheric packaging of fresh jamun fruit with different packaging material with different film characteristics with low temperature storage will be beneficial. Therefore, the present study has been planned to evaluate the modified atmosphere packaging of jamun for extending shelf life using different packaging materials and temperature conditions followed by changes in its physico-chemical qualitative aspects during storage.

Materials and Methods

Sample preparation

Fresh jamun was purchased from local vendors, cleaned and graded manually to remove the damaged and bruised fruits. Uniform sized fruits having average weight of 3.35±0.2 g measured in an electronic balance (ConTech CB-series, India) with 0.01 g accuracy and diameter of 2.5±0.3 cm (measured using slide calliper) was selected for these experiments. The bulk and true density of the fresh fruits were determined to be 659.85 kg/m^3 and 1102.14 kg/m^3, respectively and the porosity was found out to be 40%[18]. Initial moisture content of the fresh jamun was determined using the standard[19] hot air oven method and was found out to be 82.96% (wb).

Modified atmosphere packaging of fresh jamun fruits

Jamun fruit samples of 200±0.17 g weight were packed in expanded polystyrene tray with cling packaging and polypropylene (PP) packets with and without perforations (Fig. 1). The specifications of the PP packets were size: 30 cm x 10 cm, thickness 50 μm, gas permeability coefficient of 1.2 x 10^{10} [cm^3 cm/ cm^2 s (cm Hg)] for oxygen at 25°C and the trays of size 100±2 mm dia, thickness 0.25 mm. The specifications of cling film packaging were thickness: 12 μm, width: 20 cm. The number of micro-perforations maintained in the PP packets was 0, 4, 8, and 12 of size 0.03 mm each. The PP packets were perforated using a needle of 0.03 mm size, pricking at regular intervals to maintain uniformity. The area of perforation was calculated as the ratio of no. of perforations × surface area of 0.03 mm circular cross section to total surface area of the PP packets of dimension 30 cm x 10 cm. Samples were kept under refrigerated and cold storage for 30 days. The temperature and RH range of refrigerator storage was 8-10°C and 80-85% RH and cold store was 1-3°C and 90% RH (recorded with a lab thermometer and hygrometer, respectively). Polypropylene packets were thermo sealed with a manual thermo sealer. The control samples with open polythene without sealing were kept in both refrigerator and cold store to see the effect of sealing and non sealing of the materials in PP packets. The samples were kept in ambient temperature (28-30°C) also for comparison. The changes in physio-chemical properties of MAP jamun sample were evaluated in terms of headspace gas composition %O_2& CO_2, Physiological weight loss %, colour, texture, anthocyanin content, ascorbic acid content, total soluble solids (TSS) and titratable acidity. All the physical and biochemical parameters of the samples were measured at every 7 days interval i.e., at 0, 7, 14, 21, 28 and 30 days of storage.

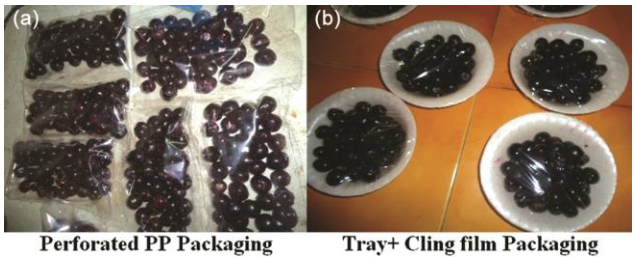

Fig. 1 (a-b) Jamun samples in different modified atmosphere packaging

Bulk density

Bulk density of the jamun fruit was determined by measuring the weight of a sample in a measuring cylinder. Jamun fruit were put in a measuring cylinder of 100 mL capacity, tapped for 10 times and then the samples were weighed in an electronic balance (ConTech CB-series, India) with 0.01 g accuracy. Bulk density was measured by taking the ratio of wt. of sample and the volume of the samples. All the

experiments were replicated thrice. True density was calculated following the toluene displacement method[18].

Physiological weight loss

The weight loss of the stored jamun in PP packets, tray and control samples during storage were determined by weighing the individual packet using a laboratory level weighing scale having 0.01 g accuracy (ConTech CB-series, India). Physiological weight loss (%) for individual packets was then calculated by taking the difference between fresh weight and the weight after storage divided by the fresh weight. Three representative samples were weighted at every stage of storage period.

Headspace gas analysis

Headspace gas of the stored jamun packets was monitored by means of a portable Gas Analyzer (PBI Dansensor Checkmate II, USA). The instrument evaluated the headspace by means of an electrochemical and an infrared sensor (sensitivity: 0.1% O_2; 0.1% CO_2, accuracy: 0.1% O_2; 0.2% CO_2) for O_2 and CO_2 concentrations, respectively. The instrument was pre-calibrated with the standard O_2 and CO_2 gases. A sampling probe containing a particulate filter and a removable needle having dual side-port holes were used to draw the sample from the package headspace with the help of an electronically controlled miniature pump. The concentrations of O_2 and CO_2 were directly read on the digital display panel of the instrument.

Colour intensity

The colour intensity (CI) in juice is determined as the sum of the absorbances at 420, 520 and 620 nm[20] using a UV-Vis spectrophotometer (Systronics Spectrop hotometer, 106, India). The absorbance of the jamun juice was measured at 420, 520 and 620 nm against a blank. Colour intensity in terms of % Bl of the juice was calculated by equation (1) and (2). The visual assessment for fruits was carried out by a five-member trained panel for spoilage severity detection and others.

$$CI = Abs\ 420\ nm + Abs\ 520\ nm + Abs\ 620\ nm \quad \ldots (1)$$

$$\%\ Bl = 100\ (A_\lambda/CI) \quad \ldots (2)$$

Where, % Bl is the percentage of blue colour (λ = 620 nm) in the overall juice colour

A_λ = the absorbance value at 620 nm,

CI= colour intensity,

Abs 420 = Absorbance measured at 420 nm wavelength,

Abs 520= Absorbance measured at 520 nm wavelength,

Abs 620 = Absorbance measured at 620 nm wavelength.

Total Soluble Solids (TSS)

Three grams of each sample was weighed and was ground with a mortar. The extracted juice was collected. Few drops of juice were put on the lence surface of the hand held refractometer (Erma 0-32 Brix, India) and reading was noted in ºBrix. Readings were taken in triplicates.

Anthocyanin content

Total anthocyanin content in the jamun fruit was determined by pH-differential spectrophotometry[20]. Briefly 1 g of jamun fruit with pulp and skin was extracted using 10 mL of 1% HCl in methyl alcohol. The extract was centrifuged at 9000 rpm for 10 min and filtered through Whatman No.1 filter paper. The above extraction steps were repeated thrice and the final volume was made up to 25 mL. Buffer reagents were prepared. pH 4.5 buffer solution was prepared by sodium acetate diluted in 960 mL distilled water. pH was adjusted to 4.5 using 20 mL of HCl. Similarly, pH 1.0 buffer solution was prepared by dissolving 1.86 g of KCl in 980 mL distilled water and for both buffers volume was made up to 1 litre. The supernatant was collected for testing. 10 mL supernatant was added to 40 mL buffer (for both the buffer solutions). Absorbance of triplicates was monitored at 520 and 700 nm for samples in both the buffers within 30 min using UV-Vis spectrophotometer (Systronics Spectrophotometer, 106, India). The total monomeric anthocyanins were calculated using the following formula (Eq, 3) and expressed as cyanidin-3-glucoside equivalent.

$$\text{Anthocyanin (mg/lit)} = \frac{A \times M \times \text{Dilution factor} \times 1000}{26900} \quad \ldots (3)$$

Where,

$A = (A_{520} - A_{700})_{\text{pH 1.0}} - (A_{520} - A_{700})_{\text{pH 4.5}}$

A_{520} = Absorbance measured at 520 nm

A_{700} = Absorbance measured at 700 nm

M= 449.2 g/mol

Dilution factor = 25.0

Total phenolic content

Total phenolic content was determined as per McDonald *et al*., (2001)[21], using Folin Ciocalteu reagent. 1 g of jamun was extracted with 10 mL of methanol: water (50:50, v/v). 0.5 mL of the diluted (1:10) extract or the standard phenol compound (Gallic acid) was mixed with 5 mL of Folin Ciocalteu reagent (1:10 diluted with distilled water) and 4 mL of aqueous Na_2CO_3 (1M). The mixture was allowed to stand for 15 min and optical density of the mixture was determined against the blank at 765 nm with the help of UV-Vis spectrophotometer (Systronics Spectrophotometer, 106). The standard curve was prepared using 0, 50, 100, 150, 200, 250 µg solutions of gallic acid per mL of methanol: water (50:50, v/v). Total phenol values were expressed in terms of the standard reference compound as gallic acid equivalent (g/100 g fresh weight of fruit).

Ascorbic acid

Ascorbic acid was determined quantitatively as per the modified 2,6-dichlorophenolindophenol (DIP) method[22]. 3% of metaphosphoric acid was prepared with distilled water. Stock ascorbic acid solution was prepared by dissolving 100 g L-ascorbic acid with 3% metaphosphoric acid and volume was made up to 100 mL. Standard ascorbic acid was made from stock ascorbic acid. Then dye was prepared by adding 50 g of 2,6 DIP to 150 mL hot distilled water containing 0.042 g of sodium bicarbonate. It was cooled and volume was made up to 200 mL in a volumetric flask with distilled water. 5 g of sample was grounded using mortar and pestle by adding 10 mL of 3% HPO_3.The sample was kept still by adding charcoal powder to absorb the colour. Five mL standard ascorbic acid solution and 5 mL of 3% HPO_3 was taken in 250 mL conical flask and mixed. It was titrated against the prepared dye solution to get the dye factor, to a pink colour end point. Ten mL aliquot sample was taken and titrated with dye to pink end point which persists for at least 15 s. Ascorbic acid content of the samples were calculated using the equation 4.

$$\text{Ascorbic acid (mg/100 g fresh fruit)} = \frac{\text{Titre} \times \text{Dye Factor} \times \text{Volume made up} \times 100}{\text{Aliquote of extract} \times \text{weight of sample}} \quad \ldots (4)$$

Titratable acidity

Ten mL of jamun fruit pulp solution was taken in a conical flask and 2 drops of phenolphthalein indicator and mixed well. It was titrated against 0.1N NaOH from burette till the pink colour disappears. Volume of the NaOH is recorded. Percent acidity is calculated from equation 5.

$$\% \text{ Titrable Acidity} = \frac{N \times V_1 \times Eq.Wt.}{V_2 \times 10} \quad \ldots (5)$$

Where,

N= Normality of titre (NaOH), mEq/mL

V_1=Volume of titre, mL

V_2= Volume of sample, mL

Eq.wt = equivalent weight of citric acid, mg/ mEq = 64.0

Assessment of microbial load

Fruits of fresh sample as well as the samples stored under MAP were evaluated for microbial load as per the standard plate count method. Jamun sample of 25 g was first homogenized using a sterilized kitchen blender (Singer India Ltd., India) and was then further diluted to get serial dilutions using saline solution. Each set of serially diluted sample was spread on to respective agar plates in a laminar flow chamber. Total bacterial load was determined using nutrient agar (Himedia) substrate and incubated at 37ºC for 24 h. The yeast and mould count were estimated by incubation in potato dextrose agar (Himedia) at 27ºC for 72 h.

Sensory analysis of MAP stored jamuns

Sensory analysis of jamun samples stored in PP packets with 4 no. of pin perforations kept under refrigerated condition (8-10°C) were conducted following scoring in 5-point scale. Twenty trained persons of varied age group were selected for scoring the samples in terms of colour, taste, flavour, texture, overall acceptability and initiation of off-smell for fresh, 10, 20, 30, 35 days of MAP stored jamun samples.

Statistical analysis

The statistical analysis of data obtained was carried out to establish the difference among the samples. All the experiments were performed in triplicate. The one-way ANOVA, multiple comparisons (Fisher's least significant-difference

test) and Duncan test were used to evaluate the significant difference of the data at $p<0.05$ using a statistical package (Minitab, 17, USA).

Results and Discussion

Headspace gas composition of modified atmosphere packaging of jamun

Headspace O_2 and CO_2 compositions of different packaging treatments are shown in Figure 2 and 3 for refrigerated storage condition (8-10ºC Temperature and 80-85% RH) and cold storage condition (1-3°C Temperature and 90% RH), respectively. Under all the packaging treatments, a sudden decrease in the O_2 composition and a rapid increase in CO_2concentration were observed from day 1 up to third day of storage. These phenomena may be attributed due to the initial adjustment of the jamun fruits to constricted environment and a higher rate of respiratory behaviour in the transient state of stabilization and equilibration[20]. The samples in all perforated PP case have attained almost equilibrium in O_2 and CO_2 gas composition up to 5 days of storage and due to the maintenance of modified atmosphere and permeability of the packaging film this condition can be prolonged up to 30 days of storage. Rai *et al.*[23] have also observed the same phenomena in case of jamun fruits in 5ºC & RH 90%. In non-perforated packages, the O_2 levels suddenly reduced to 15.55% from initial value of 20.8% up to 3rd day storage and then stabilized up to 10.5% after 5 days storage and towards the end of 30th days it tuned up to 10.8%. The non-perforated packages had accumulated more CO_2

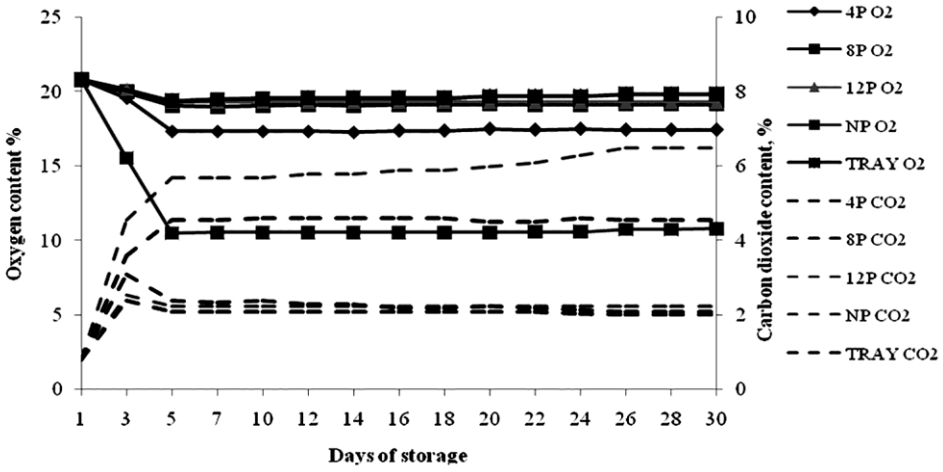

Fig. 2 — Changes in O_2 and CO_2 concentration in MAP jamun fruit in refrigerated storage condition

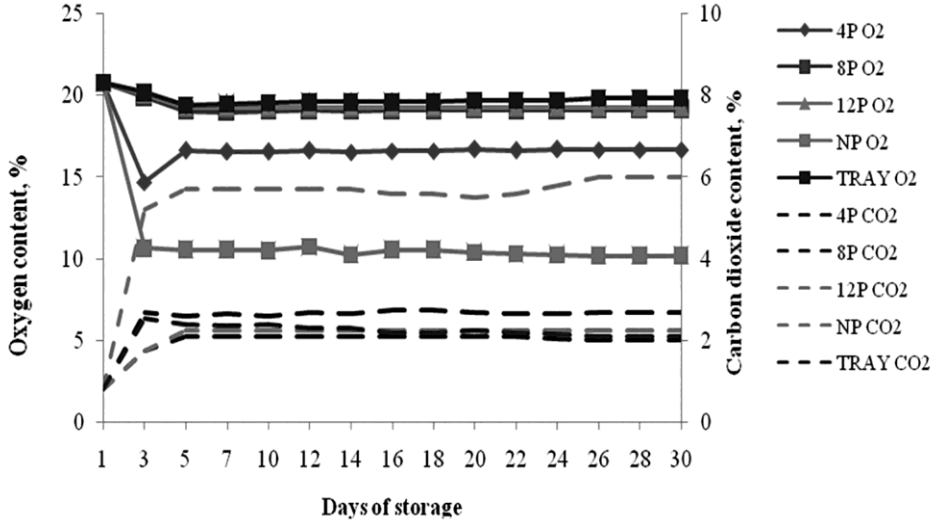

Fig. 3 — Changes in O_2 and CO_2 concentration in MAP jamun fruit in cold storage condition

concentration than other packets i.e., up to 6.5% for 30 days of storage. The O_2 concentration inside the perforated film packages reduced to 17.6% and 19.8% in 4P and 8P condition, respectively after 3 days of storage. In case of 4P PP packets, equilibrium was attained after 5 days and O_2 concentration remained almost at 17.45% and CO_2 concentration at 4.55% up to 30th day storage, which is the suitable modified atmospheric packaging gas composition range required for berry type of products[9].

The O_2 concentration in 8P & 12P PP packets up to 30 days storage remained almost constant at 19.15 and 19.3% respectively. In case of tray and cling packaging, the CO_2 level remained at 2.1% and O_2 level at 19.85% after 30 days of storage.

In case of cold storage (Fig. 3), due to maintenance of low temperature (1-3°C), the stability in the O_2/CO_2 gas concentration was attained towards the end of 3rd day in all the cases. In non-perforated jamun sample the O_2 concentration remained at 10.2% and CO_2 concentration at 6.0% up to 30 days storage. Samples with 4 perforations attained equilibrium and maintained a value of O_2 concentration of 16.67% and CO_2 concentration of 2.7%. The O_2 concentration for 8P, 12P and tray cling packets after 30th day was 19.1, 19.3 and 19.85%, respectively. Similarly, CO_2 concentration for 8P, 12P and tray cling packets after 30th day was 2.0, 2.25 & 2.1%, respectively. 4P jamun packets in cold storage maintained a modified atmospheric condition similar to the study of for berry type of fruit[9,2].

Physiological weight loss

The physiological weight loss of jamun sample after 30 days of storage was minimum for 4P and 8P perforated polythene packets both for refrigerated and cold storage condition varying within the range of 0.25-0.30% (Table 1). The one-way ANOVA suggested that there was significant ($p<0.001$) weight loss was observed after 30 days of storage under different MAP treatments with and without perforations and tray packaging, but the difference was non-significant between refrigerated and cold storage condition. The tray with cling packaging had more weight loss of jamun than perforated or non-perforated PP packets. The permeability of cling packaging may result in more water loss during storage, thus more loss in physiological weight. The control samples i.e., jamun store in PP with no sealing (i.e., open) however, resulted into maximum weight loss up to 6.81% of initial weight during 30 days of storage. Modified atmospheric packaging of jamun in all the perforated PP and tray-cling packaging recorded almost nil rate of spoilage after 30 days of storage both in refrigerated and cold storage situation. However, the control samples have recorded maximum spoilage level up to 28.38% in case of refrigerated storage. The level of spoilage in control sample in cold storage has significantly less (3.83%) than the refrigerated condition.

Table 1 — Physiological weight loss and spoilage (%) with ANOVA of Jamun stored in modified atmospheric packaging under refrigerated and cold storage temperature

Type of storage	7 days	14 days	21 days	30 days
Refrigerated storage				
4P	0.06 (0)	0.11 (0)	0.21 (0)	0.30 (0)
8P	0.05 (0)	0.10 (0)	0.15 (0)	0.25 (0)
12P	0.10 (0)	0.25 (0)	0.45(0)	0.59 (0)
NP	0.05 (0)	0.15 (0)	0.20 (0)	0.25 (0)
TC	0.30 (0)	0.75 (0)	1.09 (7.0)	1.49 (16.3)
Control	0.21 (1.96)	3.2 (8)	4.52 (16.37)	6.81 (28.38)
One-way ANOVA: F-Value: 30.40; P-Value: 0.000; R-sq: 92.40%				
Cold storage				
4P	0.050 (0)	0.0501 (0)	0.150 (0)	0.250 (0)
8P	0.049 (0)	0.099 (0)	0.1495 (0)	0.249 (0)
12P	0.050 (0)	0.250 (0)	0.400 (0)	0.550 (1.92)
NP	0.00 (0)	0.0498 (0)	0.098 (0)	0.29 (0)
TC	0.35 (0)	0.6 (0)	0.95 (0)	1.3 (3.92)
Control	0.05 (0)	0.24(2)	0.59(2)	2.17(3.83)
One-way ANOVA: F-Value: 233.27; P-Value: 0.000; R-sq: 98.94%				

NP: Non-perforated, 4P: 4 number of perforations, 8P: 8 number of perforations, 12P: 12 number of perforations, TC: Tray with cling packaging, control: Polythene without sealing (open); figure in parenthesis shows the % of spoilage.

Physical parameters

The change in bulk density, colour, TSS content of jamun stored under different packaging materials in both cold and refrigerated storage are presented in Figure 4a-6b. Initial bulk density of the jamun was 659.85 kg/m^3. It was reduced with days of storage up to 30 days in case of refrigerated storage sample (Fig. 4a). The moisture loss in the fruits during storage in cold storage lead to shrinkage of the sample and reduction in bulk density was accompanied with days of storage. Therefore, it can be suggested that jamun fruits can be stored safely up to 30 days in refrigerated (8-10°C and 80-85% RH) and under MAP storage. In case of cold storage (Fig. 4 b), the bulk density of samples was gradually reduced up to 30 days. The bulk density of control and tray-cling stored samples reduced higher as compared to PP packets.

The colour of jamuns in terms of percent blue colour (%Bl) was gradually reduced from an initial value of 73.04% to 60% and 51% in case of refrigerated and cold storage, respectively (Fig. 5a-5b). In all cases, the changes in colour are non-significant ($p<0.05$) except the control conditions in case of cold stored sample. The MAP packages of jamun with and without perforations retained better colour as compared to tray and control samples.

The TSS (%) of the jamun samples was initially 11.8°B and it was increased up to 12.5°B and 13.5°B, respectively for cold and refrigerated stored samples after 30 days of storage. The low amount of moisture loss from the fruits in MAP conditions during storage in refrigerated and cold storage caused very less amount of increase in TSS of the samples (Fig. 6a-6b). A significant difference ($p<0.05$) in the TSS content was observed between the MAP perforated package and the control samples in both refrigerated and cold storage.

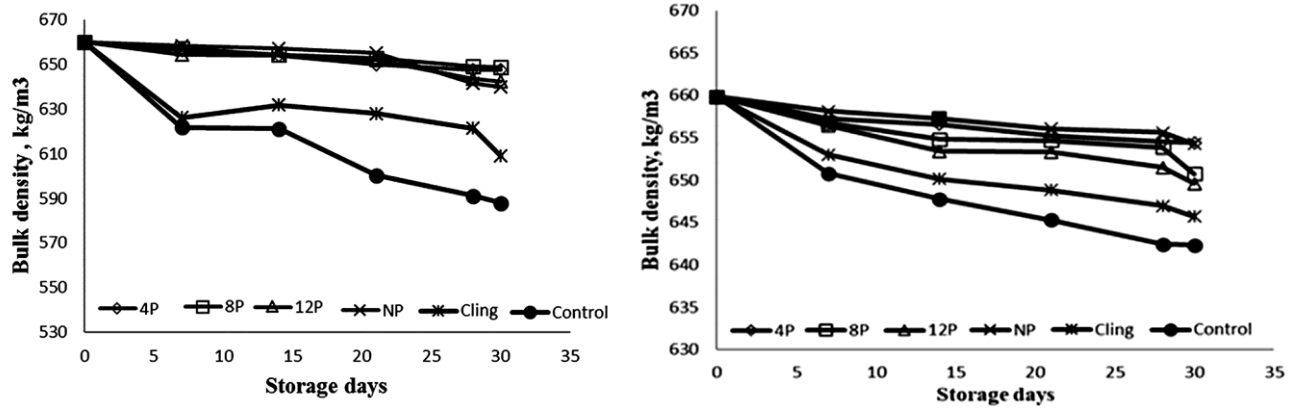

Fig. 4a — Change in bulk density of jamun stored in different packaging system in refrigerated store; (b) Change in bulk density of jamun stored in different packaging system in cold store

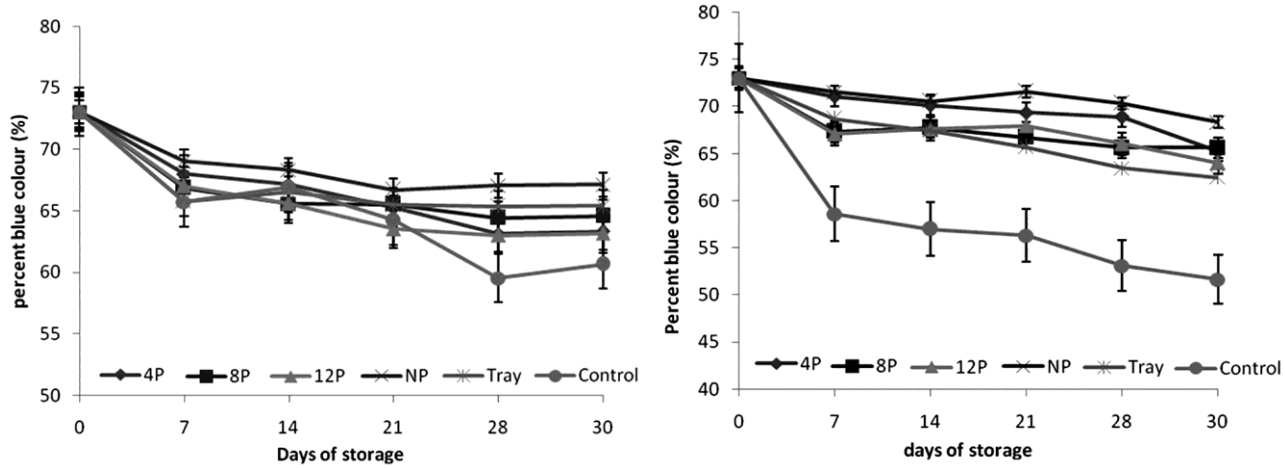

Fig. 5a — Change in percent blue colour of Jamun in different packaging system in refrigerated store; (b) Change in percent blue colour of jamun in different packaging system in cold store

Biochemical constituents of jamun

The biochemical constituents of jamun under perforated and non-perforated MAP conditions and control samples after 30 days storage in refrigerator and cold storage are presented in Table 2. The ascorbic acid content retained better in perforated PP and tray with cling packages. Its retention was found to be significantly ($p<0.05$) higher (80%) for jamuns in 4 perforation PP packets. The statistical LSD value suggested that, there is non-significant ($p<0.05$) difference in ascorbic acid content between 4P, 8P, 12 P PP packed jamun samples in refrigerated storage. On the other hand, ascorbic acid content of control sample was significantly differing from the perforated MAP packets. Tray and cling packaging retain moderately the ascorbic acid content from 38.20 to 23.86 mg/100 g fw. The statistical LSD (column) value suggest that, the ascorbic acid content of cold stored samples was non-significantly ($p<0.05$) different from refrigerated samples and more in case of cold stored samples., The total initial anthocyanin content of jamun fruits at the beginning of the study was observed to be 4.260 mg/100 g of fruit (Table 2) which gradually decreased under all the packaging treatments and temperature of storage with the progress of storage. This is in agreement with earlier reported observations on fruits and vegetables[20]. The cold stored sample gave significantly ($p<0.05$) higher retention of anthocyanin content than refrigerated. The 8P sample in cold stored condition gave maximum retention up to 92.85% of anthocyanin content even after 30 days of storage. On the other hand, non-perforated and control samples could retain only 21.69 and 9.0% of anthocyanin at the end of

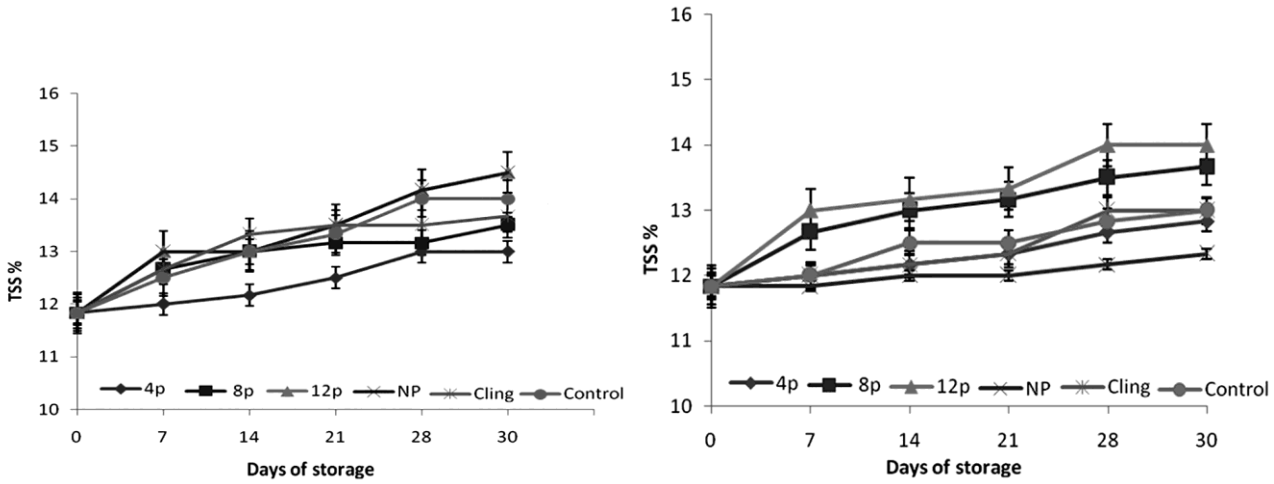

Fig. 6a — Change in TSS of samples stored in different packaging system with refrigerated storage; (b) Change in TSS of samples stored in different packaging system with cold storage

Table 2 — Biochemical constituents of Jamun after 30 days of storage under MAP

Type of packaging	Ascorbic acid (mg/100 g fw)		Anthocyanin content (mg/ 100 g fw)		Total Phenoic content (mg/100 g fw)		Titratable acidity (%)	
	RS	CS	RS	CS	RS	CS	RS	CS
Initial	38.21±0.24^{a}	38.21±0.24^{a}	4.26±0.31^{a}	4.26±0.31^{a}	536.3±14.73^{a}	536.3±12.8^{b}	1.54±0.005^{a}	1.54±0.005^{a}
4P	30.67±0.48^{b}	33.65±0.69^{b}	2.95±0.05^{b}	2.95±0.165^{b}	637.0±14.7^{b}	705.0±12.5^{b}	0.95±0.015^{b}	0.96±0.005^{b}
8P	28.15±0.03^{b}	29.98±0.05^{c}	0.88±0.06^{c}	3.95±0.07^{c}	778.3±14.7$^{b\,c}$	873.6±29.3^{b}	0.93±0005^{b}	0.98±0.011^{b}
12P	27.95±1.15^{b}	28.75±0.065^{cd}	0.69±0.03^{cd}	2.79±0.013^{bd}	780.3±11.05^{b}	877.6±17.5^{b}	1.03±0.026^{c}	0.95±0.01^{b}
NP	22.126±0.004^{c}	26.08±0.13^{d}	0.84±0.07^{c}	0.911±0.016^{e}	615.3±14.9$^{b\,b}$	615.0±11.3^{b}	0.92±0.005^{b}	0.98±0.023^{b}
Tray+Cling	23.86±0.01^{c}	29.23±0.04^{c}	1.22±0.04^{ce}	1.93±0.06^{b}	816.6±26.7$^{b\,d}$	813.6±27.7^{b}	0.87±0.005^{b}	0.94±0.005^{b}
Control	12.47±0.22^{d}	14.80±0.08^{e}	0.25±0.06^{d}	0.38±0.012^{f}	816.6±2.05$^{b\,d}$	796.0±12.8$^{b\,c}$	0.77±0.01^{d}	0.873±0.005^{b}
LSD (row)	4.07	3.27	0.50	0.93	66.0	68.0	0.079	0.059
LSD (column)	7.94		0.49		37.67		0.48	

The mean difference within the same column / same row with different superscripts are significantly different at the $p<0.05$ level; RS: Refrigerated storage, CS: Cold storage

storage. The tray with cling packaging retained the anthocyanin content to a final value of 1.22-1.93 (mg/100 g fw). The statistical LSD (column) value suggest that, the anthocyanin content of cold stored jamun samples were not significantly different from refrigerated samples, except for 8P and 12P case and more in case of cold stored samples.

The total initial phenolic content of jamun fruits was 536.3 mg/100 g fresh weight of fruit. MAP increased the phenol content of fruits during storage, both for perforated and non-perforated conditions. The increase was observed to be more for 12P and 8P samples to a value of 780.3 and 778.3. & 877.6 and 873.6 mg/100 g fresh weight, for refrigerated and cold storage condition, respectively. This phenomenon could be attributed to the higher microbial invasion as well as the lower levels of headspace CO_2 prevailing in these packages which is also reported to have an inhibitory effect on micro-organisms. On the other hand, increase in the phenolic content of nonperforated and control samples could also be solely attributed to the wound response mechanism as the damage to the stored fruits was visibly apparent after 30th day of storage. Several other studies have also reported the same trend of increase in phenolic compounds after wounding in different type of fruits and vegetables[9,11,24,25]. The reason of increase in phenolic compound by injury is attributed to production of injury signals and then further acceleration of the oxidative decomposition of sugar into erythrose 4-phosphate (E4P) and phosphoenolpyruvate (PEP).

The variation in titratable acidity among different jamun samples stored in different modified atmospheric packaging systems are almost insignificant ($p<0.05$). This indirectly indicates that the formation of any ethyl alcohol was minimized in MAP jamun packages after 30 days in both cold and refrigerated storage. However, for control sample, the variation of titrable acidity was slightly reducing to 0.77 and 0.87 as compared to the initial value of 1.54 in refrigerated and cold storage, respectively.

Total microbial load

Total bacterial load and yeast & mould count of stored jamun in different perforated, non-perforated and control samples after 30 days storage was found to be lower in perforated PP and non-perforated packages as compared to control samples (Table 3). Bacterial load was less i.e., within 1.39-2.11×10^{4}cfu/g in case of 4 perforation samples for cold and refrigerated sample, respectively. The control sample i.e., stored in open in refrigerated and cold storage accounted for maximum microbial load in the range of 11.4-11.7×10^{5}cfu/g. Therefore, modified atmospheric packaging of jamun had a significant ($p<0.5$) effect on the bacterial load on the stored samples. This is also in accordance with the result obtained by Rai *et al.*[23]. The growth of yeast and mould was higher in case of control and followed with tray cling packaging after 30 days (i.e., about 11.08×10^{4}cfu/g in refrigerated storage and 4.25×10^{4}cfu/g in cold storage). The statistical LSD test suggested that the total microbial load in case of control samples both in cold and refrigeration storage are significantly ($p<0.05$) higher than MAP storage. Among MAP packets the 12 perforations packets accounted for maximum microbial load as compared to other combinations. Therefore, according to the microbial analysis the 4P, PP modified atmospheric packaged jamun samples stored for 30 days in cold storage (1-3°C, 90% RH) can be able to produce good quality and safe produce.

Table 3 — Analysis of bacterial, yeast and mould load count of jamun stored under MAP after 30 days storage

Sample	Bacterial Load count (10^4x cfu/g)		Yeast and mould count (10^4x cfu/g)	
	RS	CS	RS	CS
4P	2.11±0.32^a	1.39±0.15^a	2.77±0.007^a	2.58±0.02^b
8P	3.5±0.72^b	3.45±0.30^b	4.42±0.007^b	2.67±0.065^b
12P	4.37±0.68^c	3.77±0.32^b	6.83±0.04^c	3.25±0.007^c
NP	3.0944±0.95^b	1.2411±0.41^a	2.67±0.33^a	0.08±0.04^a
Tray + Cling	3.47±0.53^b	3.17±0.66^b	11.08±0.056^d	4.25±0.021^d
Control	117.97±0.32^d	114.19±4.16^c	18.58±0.035^e	7.83±0.07^e

The mean difference within the same column with different superscripts are significantly different at the $p<0.05$ level. RS: refrigerated storage, CS: cold storage.

Table 4 — Sensory scores of Jamun samples under MAP storage

Sample	Days of storage				
	Fresh	10 days	20 days	30 days	35 days
Colour	9.5±0.05	9.0±0.03	8.72±0.20	8.01±0.13	7.5±0.05
Taste	9.02±0.32	8.84±0.15	8.25±0.07	7.25±0.02	5.90
Flavour	9.05±0.539.05	8.02±0.66	7.51±0.056	6.80±0.021	6.25
Texture	9.52±0.32	7.88±4.16	7.25±0.035	6.90±0.07	6.05
Overall acceptability	9.25±0.24				
		8.5±0.22	8.02±0.23	7.05±0.16	6.0±0.40
Off smell	-	-	-	Slightly present	Initiated

The mean difference within the same row with different superscripts are significantly different at the $p<0.05$ level.

Sensory analysis

Sensory score of MAP stored as well as fresh jamun samples in terms of colour, taste, flavour, texture, overall acceptability were given in Table 4. Fresh sample scored highest in all the sensory parameters with overall acceptability of 9.25. samples having 10 days storage had scored highest in colour (9.0) with flavour 8.02 and overall acceptability 8.5. Similar trend was also observed for 20 days of storage having flavour and texture score slightly low i.e., 7.51 and 7.25, respectively. At 30 days of storage the sensory score for colour was 8.01 and texture and flavour were slightly lower to 7.0, therefore giving an overall acceptability of 7.05 and there was an initiation of off-smell started which were absent before 30 days storage. The sensory score of 35 days storage samples were decreased in terms of taste (5.90), texture (6.05), taste (6.25), overall acceptability of 6.0 and there was off-smell development, which was considered as un-acceptable for consumption. Therefore, MAP of jamun samples in 4 perforations, pp packet, refrigerated storage condition gave an acceptable sensory score above 7.0 up to 30 days storage and was consider acceptable for consumption.

Conclusion

Modified atmospheric packaging enhanced the shelf life of fresh jamun. It could be stored for up to 30 days in case of cold and refrigerated storage. The O_2 content of the packets decreased and CO_2 content increased with no of days of storage. With some initial adjustment of the samples with the environment up to 3-5 days the gas composition then equilibrated up to 30 days of storage. The physiological weight loss was lesser for 4P and 8P PP packets ranging between 0.25-0.35% up to 30 days storage both in cold and refrigerated storage. In expanded polystyrene tray with cling packaging physiological weight loss was more as compared to polythene packets. Anthocyanin content (mg/100 g sample) was retained more in cold stored sample and 8P polythene packets. Same trend is followed with ascorbic acid content of the sample. Microbial load was less i.e., within $1.39\text{-}2.11 \times 10^4$cfu/g in case of 4P sample for cold storage and refrigerated sample. The control sample i.e., stored in open in refrigerated and cold storage accounted for maximum microbial load in the range of $11.4\text{-}11.7 \times 10^5$cfu/g. MAP of jamun samples in 4 perforations, pp packet, refrigerated storage condition gave an acceptable sensory score above 7.0 up to 30 days storage and was consider acceptable for consumption. From all the physical and biochemical analysis conducted, it was suggested that storage of fresh jamun in modified atmospheric packaging with 4 pin holes in polypropylene packets in cold storage (1-3°C Temperature and 90% RH) gave the best result and can be stored up to 30 days.

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Conflict of Interest

There is no conflict of interest among the authors regarding publication of the manuscript.

Authors' Contributions

MM has contributed in formulation, experimentation and correction of the manuscript; SB had contributed in experimentation and writing of the manuscript; RNN had contributed in analysis of physico-chemical properties, manuscript correction and compilations; MKP had contributed in

formulations and correction of the manuscript; and SKD had contributed in providing lab facilities and financial support in overall accomplishment of the study.

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