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Permeability of the in-package parameters and their correlations in modified atmospheric packaging of strawberry CV. Sweet Charlie

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Abstract
The properties of in–package parameters of MAP *viz.*, O_2, CO_2, relative humidity and temperature were studied under modified atmospheric packaging (MAP). Easily available different low cost packaging materials *viz.*, low density polyethylene (LDPE) 25, 50 and 75 micron, polypropylene (PP) 25 micron, cellophane paper and Nalgene bottle under the ambient temperature condition were used. The fluctuations of important parameters in the in-package environment of the MAP were recorded using different sensors (Vernier CO_2, O_2, RH Sensor, and Vernier Stainless Steel Temperature Probe) supported with the data analysing software Logger *Pro* 3.9. The correlation study was performed using the sensor generated data to infer the existing inter–relationship of various parameters for the respective packaging materials. PP showed a higher permeability for CO_2, O_2 and RH between the in – and out – package environment. PP showed its higher permeability for CO_2, O_2 and RH between the in – and out – package environment. Among the LDPE films, the LDPE 50 micron showed an optimum permeability for O_2, CO_2, as well RH. As a conclusion of the study, the comparative permeability of different packaging films were illustrated with respect to various components of MAP and their probable influence on the strawberry fruit quality enhancement may further be studied.

Keywords: strawberry, MAP, films, sensors, permeability, correlation

1. Introduction
Strawberry (*Fragaria* × *ananassa* Duch.) is one of the most attractive, delicious, refreshing and nutritious soft fruit liked mainly for its delicate flavour and appearance. The edible portion accounting about 98% of the fruit is contains nutritionally important diverse elements. Owing to its deep red colour it is a rich source of anthocyanin possessing high antioxidant activity (Sun *et al.*, 2002) [2] which is 1.3 times more than that of oranges, twice that of red grapes and twelve times that of apples and bananas (Guo *et al.*, 1997) [1]. Antioxidant properties of strawberry have been mostly attributed to its polyphenol and vitamin content. Strawberry has non climacteric ripening behavior of fruit. The rate of ethylene evolution is low, however, due to its characteristic high respiration rate (50-100 ml CO_2 per kg of fruits per hour at 20 °C), the fruits are highly perishable and can be stored only for a quite short duration (Nunes *et al.*, 2006) [6]. This characteristic of strawberry fruits limits its further expansion and popularity among farmers *vis-a-vis* the traders in generally about 20-50%. Post–harvest loss owes to the high respiration and the post–harvest decay in strawberry depending upon harvesting month, fruit maturity, transportation distance and method of packaging (Mingchi and Kojimo, 2005) [4]. The packaging material has a significant role for better shelf life of the packed product as well as to attract the consumers. MAP using different easily available polymeric films is one of the best and low cost technology to retain the shelf-life and quality of strawberry. The modified atmosphere (MA) has a gaseous composition around fruit that differ from the normal air *i.e.*, 78.08 per cent N_2, 20.95 per cent O_2 and 0.03 per cent CO_2 (Kader, 1992) [3]. Such a change in the gaseous atmosphere can be attributed to the factors like respiration and other biochemical processes of the produce and permeation of gases through the packaging film. This slows down the growth of aerobic microbes and the speed of oxidation reactions. A well-known benefit of MAP is to reduce the water loss by creating high humidity inside the packaging and on that account the produce maintains freshness comparatively for a longer period.

MAP is a dynamic process where respiration and the feed – back inhibition of respiration occurs simultaneously owing to the permeability of the packaging material. The most crucial factors responsible for MAP of the fruits are the permeability of the packaging films and the respiration rate of the packed fruit. The permeability of the packaging film is mainly dependent on the thickness of the film and type of the polymer. The various physico-chemical properties of the stored fruits are highly dependent on the extent of modification of the environment inside the package (i.e.O_2, CO_2, RH and temperature), which ultimately depends on the permeability of different packaging materials. An improvement in strawberry fruit quality packed with LDPE 50 and 75 micron packaging films was reported under MAP condition (Panda *et al*., 2016) [8]. In strawberry Zhang *et al.* (2003) reported the optimum concentration of CO_2 (16%) and O_2 (2.5%) gas in modified atmospheric condition. These primary components of MAP behaved differently for different packaging materials. The O_2 concentration increased quickly, while that of CO_2 decreased in first 12h, consequent of the concentration difference between in- and out-packages with the extension of storage time, due to respiration, the concentration of O_2 decreased, while that of CO_2 shot up. After 18 hour, the very small change in O_2 and manifested a balance which reflected that MAP could inhibit respiration of strawberry. Keeping the facts in view the study was planned to evaluate the permeability of different packaging materials for the environmental parameters (CO_2, O_2, relative humidity and temperature) greatly influencing the modified atmosphere inside a package and ultimately may be the various physico-chemical qualities of the packed fruits of strawberry.

2. Materials and Methods

This study was conducted in the Department of Horticulture, CCS HAU, Hisar during March 2015. Fruits of strawberry cv. Sweet Charlie were harvested approximately at 3/4th maturity stage during the morning hours. About 150g freshly harvested fruits were kept in plastic punnets. Each of the following packaging films was wrapped around the punn*et al*ong with the four sensor probes and the packages were made air tight manually. In one treatment the fruits were packed in the *Nalgene* bottle and made air tight by inserting the sensor probe in place of the lid. All the sensors were connected to the data collecting device, which was connected to the computer. The data collecting software (*Logger Pro 3.9*) stored the data and represented in graphical forms individually for each parameters with respect to time scale.

2.1. Sensors and the software

- Data collection software: *Logger Pro 3.9*
- Sensors: i) *Vernier CO_2 Gas Sensor*
  ii) *Vernier O_2 Gas Sensor*
  iii) *Vernier RH Sensor*
  iv) *Vernier Stainless Steel Temperature Probe*

2.2 Low Cost Packaging materials used

T1: Low Density Poly Ethylene (LDPE) 25 micron
T2: Low Density Poly Ethylene (LDPE) 50 micron
T3: Low Density Poly Ethylene (LDPE) 75 micron
T4: Polypropylene (PP) 25 micron
T5: Cellophane Paper
T6: *Nalgene* bottle (250 ml volume)

The recorded sensor data was analyzed by using IBM – Statistical Package for Social Sciences (SPSS) version 24 (IBM Corp, 2016) [2] to infer the correlation of different parameters of MAP for the respective packaging materials. Pearson's coefficient of correlation was estimated and significance was than tested using t-test at 95% level of significance.

3. Results & Discussions

The findings of this experiment illustrated the properties of individual packaging treatments for each of the major parameters playing a key role in modifying the in-package environment under the following headings.

3.1. Carbon dioxide

The data pertaining to the permeability of CO_2 in different packaging materials presented in Fig.1 revealed that in all the treatments the CO_2 concentration in the in-package environment of the packed strawberry fruits continued increasing at differential rate. In the *Nalgene* bottle, a steady increase was recorded up to the 9th hour (4.64%), reaching maximum (4.82%) on the 13th hour. The CO_2 concentration declined gradually in the in-package environment after the 15th hour, whereby it became almost constant. In LDPE 75 micron film package, the CO_2 concentration increased steadily up to the 14th hour (4.81%) and became almost constant attaining the maximum at the 16th hour (4.99%) and then declined gradually. The rise of CO_2 concentration in LDPE 50 micron film could be illustrated in three different phases. Up to the 3rd hour (1.52%) a rapid increase was noticed, which was followed by a comparative slower increase till the 12th hour (2.93%) and until the 23rd hour (3.27%). Similar trend of increase in CO_2 concentration was recorded for LDPE 25 micron film as that of the LDPE 50 micron film. Up to the 2nd hour (1.05%) a rapid increase was noticed, which was followed by a comparative slower increase till the 9th hour (2.16%) and then constantly up to the 23rd hour (2.63%). Likewise in cellophane paper packaging, the CO_2 concentration increased till the 17th hour (2.84%) and then declined comparatively at slower rate. In PP 25 micron packaging film, the rise in CO_2 concentration was comparatively at slower rate till 9th hour (0.16%), there after CO_2 concentration rose at a comparatively slower rate and reached maximum level of 1.46 per cent at the 23rd hour. Strong and highly significant positive correlation coefficients' (0.87, 0.91, 0.88, 0.96, 0.89 and 0.74) were observed between the CO_2 concentration and time for LDPE 25 micron (Tab.1), LDPE 50 micron (Tab.2), LDPE 75 micron (Tab.3), PP 25 micron (Tab.4), cellophane paper (Tab.5) and Nalgene bottle (Tab.6), respectively.

In all the packaging treatments, the CO_2 concentration followed a steady increasing trend in the early phases because of the very high respiratory behavior of strawberry fruits. The same could be signified from the illustrated data of correlation coefficient for all the packaging treatments. On attaining the optimum level of CO_2 concentration on account of the feedback mechanism of CO_2, the respiration rate declined, the CO_2 concentration could not increase so rapidly. Similar trend in CO_2 concentration was reported by Nielsen *et al*. (2008) [5] in strawberry fruits under MAP. In Nalgene bottle, after a period of constant CO_2 concentration started decreasing probably due to initiation of anaerobic respiration by the fruit tissues at a reduced oxygen level. In films having greater permeability of CO_2, the time taken by CO_2 for reaching constancy was quite more than that of the films having lesser permeability. Owing to maximum permeability the rise in CO_2 concentration in the PP film was very slow, while in LDPE films, permeability of CO_2 increased with a decrease in film thickness. Ornelas-Paz *et al*. (2012) also reported such results in peppers.

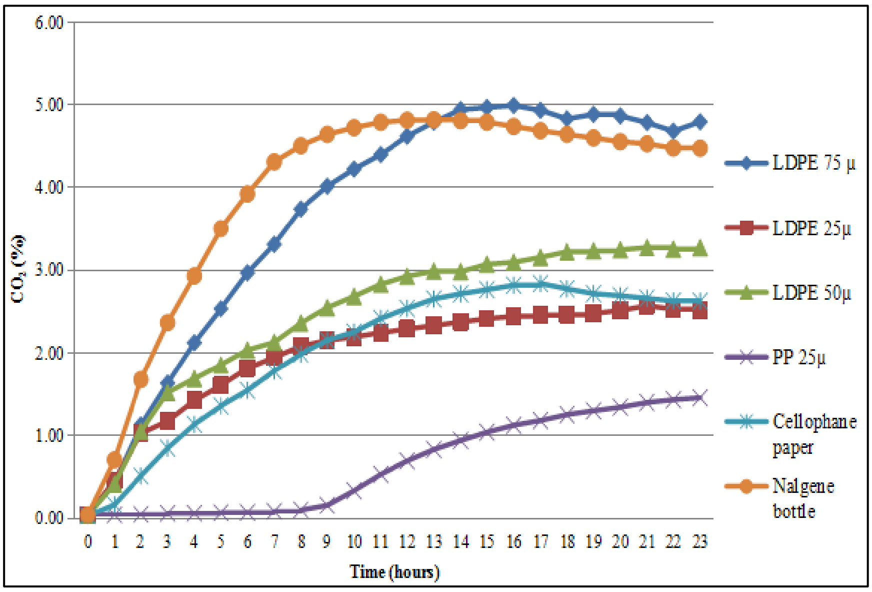

Fig 1: Effect of various packaging film on the CO2 concentrarion in modified atmospheric packaging of strawberry cv. Sweet Charlie

3.2. Oxygen

The differential inclination of the O_2 concentration for different packaging materials could clearly be illustrated from the Fig. 2. Further, with the passage of time, the O_2 concentration had a decreasing trend in all. This decrease was faster in the initial hours and after reaching a certain level, declined at reduced rate finally attaining the constancy. In *Nalgene* bottle O_2 concentration decreased fastest in and finally touched zero level in the in-package atmosphere at the 21st hour revealing its lowest permeability to O_2. In LDPE 25 micron film, a sharp reduction in O_2 concentration was recorded up to the 6th hour (10.59%) and followed a comparatively slower decreasing rate till the 23rd hour (5.89%). In LDPE 50 micron a steady decrease in O_2 concentration was recorded from the zero hour (20.83%) till the 23rd hour (8.33%). This trend with maximum O_2 concentration on the zero hour (20.73%) and minimum on the 23rd hour (11.36%) of storage was also recorded for the cellophane paper. LDPE 75 micron film illustrated the comparatively slower rate of decrease in O_2 concentration from the zero hour (20.22%) to the 23rd hour (14.75%). PP 25 micron film having maximal permeability to O_2 maintained its maximum concentration (20.77%) compared to all other packaging materials which reached minimum (17.59%) at the 23rd hour. Strong and highly significant negative correlation coefficients' were observed between the O_2 concentration and time (0.90, 0.93, 0.97, 0.96, 1.0 and 0.94), as well as between the O_2 and CO_2 concentrations (0.99, 0.98, 0.93, 0.94, 0.93 and 0.91) for LDPE 25 micron (Tab.1), LDPE 50 micron (Tab.2), LDPE 75 micron (Tab.3), PP 25 micron (Tab.4), cellophane paper (Tab.5) and Nalgene bottle (Tab.6), respectively.

On account of the utilization of the limited O_2 present inside the packages during the process of respiration, its concentration went on decreasing in all the packages. In packaging materials with lesser permeability to O_2, the constant level was reached earlier than those having greater permeability. In Nalgene bottle having almost zero permeability, the O_2 concentration rapidly declined and reached zero level. In PP 25 micron film, the O_2 concentration remained at a higher level than that of the other films. In all the packaging materials similar trend of decreasing O_2 concentration was recorded. Earlier such results in strawberry fruits in MAP were reported by Nielsen *et al*. (2008) [5]. The permeability of O_2 increased with the decrease in thickness of the packaging films. Present results found the support of the findings from Ornelas-Paz *et al.* (2012). The mentioned correlation coefficients between the O_2 concentration and time as well as the O_2 and CO_2 concentrations justified so.

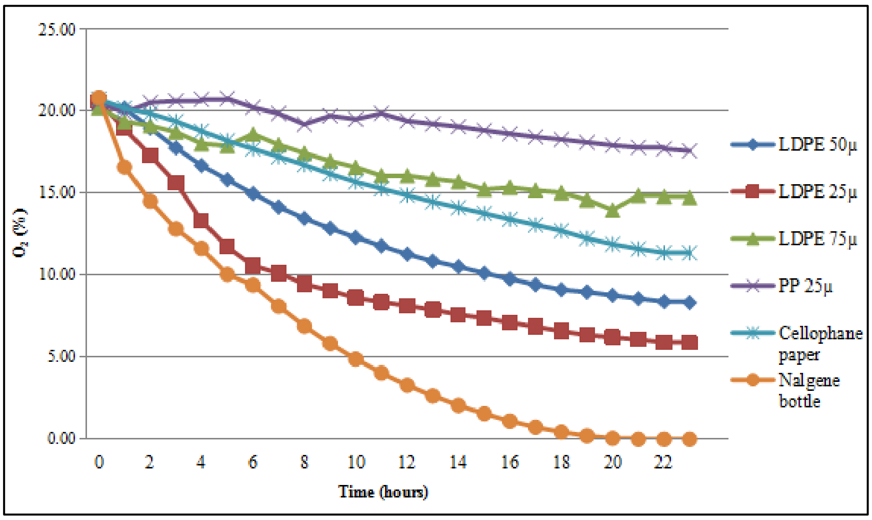

Fig 2: Effect of various packaging film on the O2 concentrarion in modified atmospheric packaging of strawberry cv. Sweet Charlie

3.3. Relative Humidity

The change in RH in the in-package environment of the modified atmospherically packed strawberry fruits is represented in Fig. 3. Generally, RH depicted a sharp rise till the 2nd hour but instantly became slower and moved on to a constant level. Exactly similar pattern was noticed for almost all packaging materials except the *Nalgene* bottle and PP 25 micron film. In *Nalgene* bottle, the RH was almost constant from the initial hours and reached the maximum value at 23rd hour (58.56%) suggesting its lowest permeability to moisture. The maximum permeability was observed in LDPE 25 micron film where a steady increase was recorded up to the 2nd hour (88.64%) and reached maximum on the 23rd hour (92.70%) whereas, the minimum on the zero hour (62.73%). In LDPE 50 micron film, the minimum RH was noted on zero hour (52.51%) which steadily increased up the 2nd hour (82.91%) and constantly up to the 23rd hour (89.54%). In case of LDPE 75 micron film, the steady rise in RH was up to 2nd hour (77.33%) and then constantly up to 23rd hour (86.54%). In cellophane paper, the sharp rise was up to the 1st hour (58.57%) and then gradually it followed the constant trend as that of the LDPE 75 micron film till the 23rd hour (87.18%). PP 25 micron film, RH exhibited a variable rate of increasing trend up to the 11th hour (74.61%) and then it followed the constant trend till the 23rd hour (74.95%). The in-package relative humidity in MAP as a measure of the moisture level is prominently affected by the transpiration and other metabolic processes of the cells of any fruit. During the early phase of storage, rapid increase in RH might be attributed to the rapid metabolic processes. As the relative humidity inside a package reaches to a certain peak level, due to its feedback mechanism the moisture loss from the fruits is checked. Hence, a constant trend in relative humidity is observed after a certain time. As the temperature increased, an increase in relative humidity was noticed in all the packaging materials. This might be attributed to the increased moisture holding capacity of the in-package air because of the expansion of volume as a consequence of increased temperature. With the increase in thickness of the packaging film, the water vapors transmission and permeability rate decreased. Similar trend was inferred earlier in the study of peppers by Ornelas-Paz *et al.* (2012). From the correlation study it could be implied that, moderate to high positive as well as significant correlation of RH with time were recorded for LDPE 25 micron (Tab.1), LDPE 50 micron (Tab.2), LDPE 75 micron (Tab.3), PP 25 micron (Tab.4), cellophane paper (Tab.5) and Nalgene bottle (Tab.6) with correlation coefficients of 0.59, 0.62, 0.73, 0.90, 0.75 and 0.54, respectively. RH was having high significant and positive correlation with CO_2 concentrations with coefficient values of 0.80, 0.82, 0.86, 0.87 and 0.84, whereas negative with that of O_2 with coefficient values of 0.75, 0.72, 0.80, 0.80 and 0.77 for LDPE 25 micron (Tab.1), LDPE 50 micron (Tab.2), LDPE 75 micron (Tab.3), PP 25 micron (Tab.4), cellophane paper (Tab.5), respectively. This signified the result discussed above. Nalgene bottle showed no correlation, either with O_2 or CO_2.

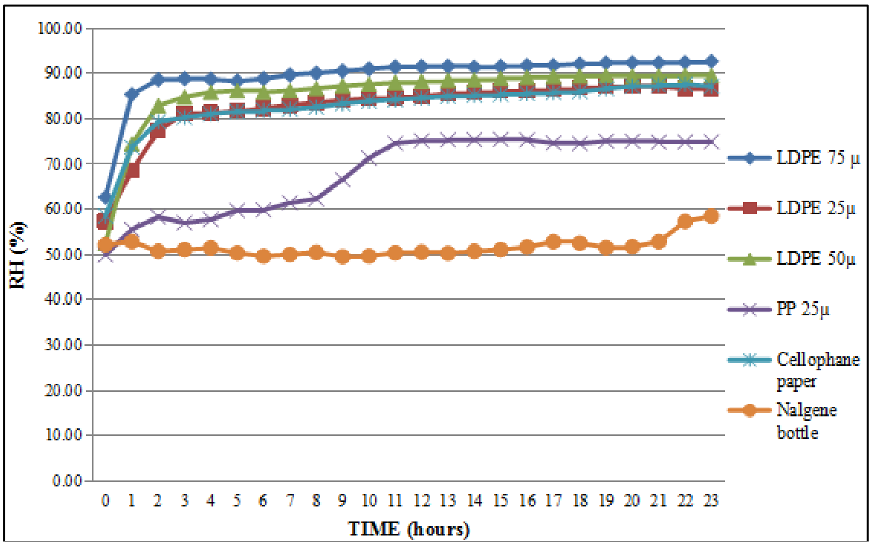

Fig 3: Effect of various packaging film on the RH (%) in modified atmospheric packaging of strawberry cv. Sweet Charlie

Table 1: Correlations among various parameters for packaging material LDPE 25µ film

	Time	LDPE 25µ O_2	LDPE 25µ CO_2
Time	1		
LDPE 25µ O_2	-.895**	1	
LDPE 25µ CO_2	.867**	-.992**	1
LDPE 25µ RH	.587**	-.746**	.799**
LDPE 25µ Temp	-.779**	.430*	-.382

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Table 2: Correlations among various parameters for packaging material LDPE 50µ film

	Time	LDPE 50µ O_2	LDPE 50µ CO_2	LDPE 50µ RH	LDPE 50µ Temp
Time	1				
LDPE 50µ O_2	-.963**	1			
LDPE 50µ CO_2	.905**	-.981**	1		
LDPE 50µ RH	.616**	-.720**	.821**	1	
LDPE 50µ Temp	-.941**	.952**	-.915**	-.643**	1

Table 3: Correlations among various parameters for packaging material LDPE 75µ film

	Time	LDPE 75µ O_2	LDPE 75µ CO_2	LDPE 75µ RH	LDPE 75µ Temp
Time	1				
LDPE 75µ O_2	-.965**	1			
LDPE 75µ CO_2	.878**	-.934**	1		
LDPE 75µ RH	.726**	-.799**	.875**	1	
LDPE 75µ Temp	-.793**	.703**	-.453*	-.262	1

Table 4: Correlations among various parameters for packaging material PP 25µ film

	Time	PP 25µ O_2	PP 25µ CO_2	PP 25µ RH	PP 25µ Temp
Time	1				
PP 25µ O_2	-.956**	1			
PP 25µ CO_2	.964**	-.941**	1		
PP 25µ RH	.900**	-.807**	.865**	1	
PP 25µ Temp	.552**	-.516**	.459*	.341	1

Table 5: Correlations among various parameters for packaging material Cellophane Paper

	Time	Cellophane Paper O_2	Cellophane Paper CO_2	Cellophane Paper RH	Cellophane Paper Temp
Time	1				
Cellophane Paper O_2	-.995**	1			
Cellophane Paper CO_2	.888**	-.927**	1		
Cellophane Paper RH	.746**	-.772**	.836**	1	
Cellophane Paper Temp	-.694**	.644**	-.334	-.213	1

Table 6: Correlations among various parameters for packaging material Nalgene Bottle

	Time	Nalgene Bottle O_2	Nalgene Bottle CO_2	Nalgene Bottle RH	Nalgene Bottle Temp
Time	1				
Nalgene Bottle O_2	-.939**	1			
Nalgene Bottle CO_2	.736**	-.911**	1		
Nalgene Bottle RH	.536**	-.274	-.030	1	
Nalgene Bottle Temp	-.774**	.561**	-.187	-.725**	1

3.4. Temperature

The temperature variation inside each modified atmospheric package during the period of investigation was depicted in the Fig. 4. Almost in all the packaging films more or less a similar trend of constant variation in the in-package temperature was observed. For LDPE 75 micron film, the maximum temperature (29.99 °C) was noted on the 7^{th} hour. During the whole experimental period the minimum temperature was recorded on the 22^{nd} hour (21.46 °C) in LDPE 50 micron. The variation in temperature was not regulated by the modification in the in-package atmosphere; rather it was because of the variation in atmospheric temperature. Such variation affects the modified atmosphere by regulating the relative humidity level along with various metabolic activities directly. No such strong evidences for temperature, which could have been correlated with the permeability of various packaging films, could be established.

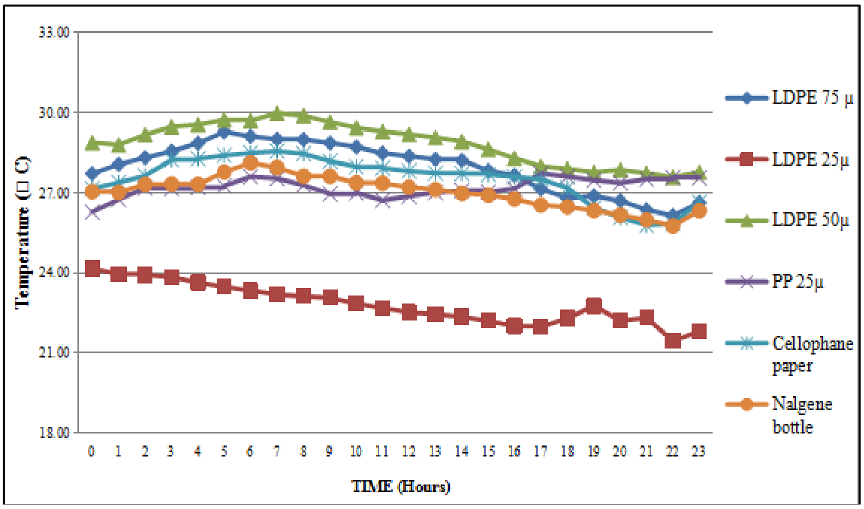

Fig 4: Effect of various packaging film on the temperature variation (Degree Celcius)in modified atmospheric packaging of strawberry cv. Sweet Charlie

4. Conclusion

The use of different packaging materials with variable permeability levels largely regulates the modification strategies of the in-package environment, which may affect the various physico-chemical properties of packed strawberry fruits. PP 25 micron was found to have the lowest concentration for CO_2, highest concentration of O_2 and a comparatively lower rise for RH at the end of the 24th hour. It indicated its higher permeability for CO_2, O_2 and RH between the in – and out – package environment. Among the different LDPE films, LDPE 75 micron recorded the maximum rise in CO_2 concentration followed by the LDPE 50 and 25 micron films. For O_2 concentration LDPE 75 micron film showed the maximum concentration followed by LDPE 50 and 25 micron and for relative humidity LDPE 25 micron showed highest increase followed by LDPE 50 and 75 micron films. Hence, the LDPE 50 micron film showed an optimum permeability for O_2, CO_2, as well RH. The cellophane paper followed a similar trend as that of the LDPE films for most of the components of MAP. The in-package variation in temperature was not affected by different packaging films; rather it was due to the variation in outside temperature. The correlation study inferred the existing inter – relationship of various parameters for the respective packaging materials. This report may be referred as a base material for extensive studies on various packaging materials for delicate fruits like strawberries.

5. Acknowledgement

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